# Center for Space Telemetering and Telecommunications Research

Program Review

NASA Grant: NAG 5-1491



Prepared by:

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# Program Review: Telemetering and Telecommunications Research

Stephen Horan
Director, Telemetering and Telecommunications Program

# Program Overview

- Topics
  - NMSU Background
  - Telemetering and Telecommunications Program
  - Grant History
  - Faculty & Staff
  - Facilities
  - Review Program

# NMSU Background

- NMSU is the Land Grant University and Space Grant University
- Federally-designated Minority University
- Carnegie-I Research University
- Statistics (Fall 1996):
  - enrollment = 14748 students
  - ABET-accredited College of Engineering

# NMSU Background

- Student Ethnicity
  - African American 2%
  - American Indian 3%
  - American Oriental 1%
  - Hispanic 34%
  - Other 60%

# Telemetering & Telecommunications Program

- Senior-level courses in Analog & Digital Communications
- Graduate-Level courses in Communications Theory, Digital Communications, Coding (Channel & Source), Satellite Communications, Telemetering Systems
- MSEE and Ph.D. degree programs

# Telemetering & Telecommunications Program

- Full-time & part-time students, off-campus programs at HAFB, KAFB, NTU
- Average 5-6 MSEE degrees and 2 Ph.D. degrees awarded each year
- Research Programs with
  - NASA (Telemetering & Telecommunications, NASA Space Grant, ACTS Propagation Experiment)

# Telemetering & Telecommunications Program

- Research Programs (cont.)
  - NSF (tape recording technology)
  - Rome Labs (signal processing)
- Chaired Professorship in Telemetering and Telecommunications funded by IFT, State of New Mexico, and industry
- Designated Center of Excellence in Telemetering Systems by the IFT

# Grant History

- Major research funding comes from NASA NAG 5-1491
  - Continuous since 1990
  - Frank Carden and William Osborne were previous Pis
- Related funding from
  - NSF, Sandia, IFT, Rome Labs

# Faculty & Staff

- Faculty
  - Stephen Horan, Director
  - William Ryan, Associate Director
  - Sheila Horan
  - Phillip DeLeon
  - James LeBlanc
  - Thomas Shay

# Faculty & Staff

- Staff
  - Janice Apodaca, Secretary
  - Lawrence Alvarez, Technician
- Students
  - 4 Undergraduates
  - 10 Graduate Students

# Facilities

- Faculty Offices in Thomas & Brown Hall and Goddard Hall
- Student Offices in Thomas & Brown Hall and Goddard Hall
- Telemetering Center is a central suite
  - Director's Office - Secretary
  - Research Laboratory - Technician

# Facilities

- Laboratory
  - hardware development and testing area
  - software simulation area
- Future (hopefully)
  - Telemetering and Telecommunications Program to take over the majority of Goddard Hall (present Engineering Technology Department)

# Facilities

- Presently developing IFT-funded academic communications and signal processing laboratory
  - 5 PCs
  - Labview
  - Satellite Tool Kit
  - Matlab
  - radio equipment

# Review Program

- 8:30-9:00 Introductions
- 9:00-9:30 - Program Overview
- 9:30-10:30 - Small Satellite & Related Work
- 10:30-10:45 - Break
- 10:45-12:00 - Bandwidth-Efficient Modulation Techniques
- 12:00-1:30 - Lunch
- 1:45-2:30 - Coding Techniques
- 2:30-3:00 - DAMA Development
- 3:00-3:15 - Break
- 3:15-4:00 - Tours & Demonstrations
- 4:00-5:00 - Wrap-up Review
- 5:00- Adjourn

# Small Satellite Technology

Stephen Horan, Phillip DeLeon, and
Thomas Shay

# Small Satellite Access of the Space Network

- Topics
  - Purpose
  - Activities
  - Current Year Highlights
  - Plans for Next Year
  - Future Plans

# Purpose

- To assist the small satellite community in utilizing the SN for communications services rather than proprietary ground stations
  - reduce costs associated with communications system design
  - assist users in gaining access when high-priority users are being supported

# Activities

- Orbital Access
  - predicting when a fixed antenna system on a user satellite can access a TDRS
  - evaluation of communications performance
- Spacecraft Testing
  - testing communications concepts with on-orbit spacecraft

# Activities

- DAMA
  - Develop concept for how on-demand services might be scheduled
  - Develop concept for Doppler tracking using advanced DSP concepts
- RF Testbed
  - Develop RF satellite simulation testbed from NMSU

# Current Year Highlights

- Orbital Access
  - looked at 600 km - 1200 km orbits over a 30-day period using Satellite Tool Kit to improve methodology from "home-brew" simulations of the previous years
  - Added TDRS-Z to coverage predictions
  - Use SNUG Rev. 7 data to evaluate data throughput

# Orbital Access

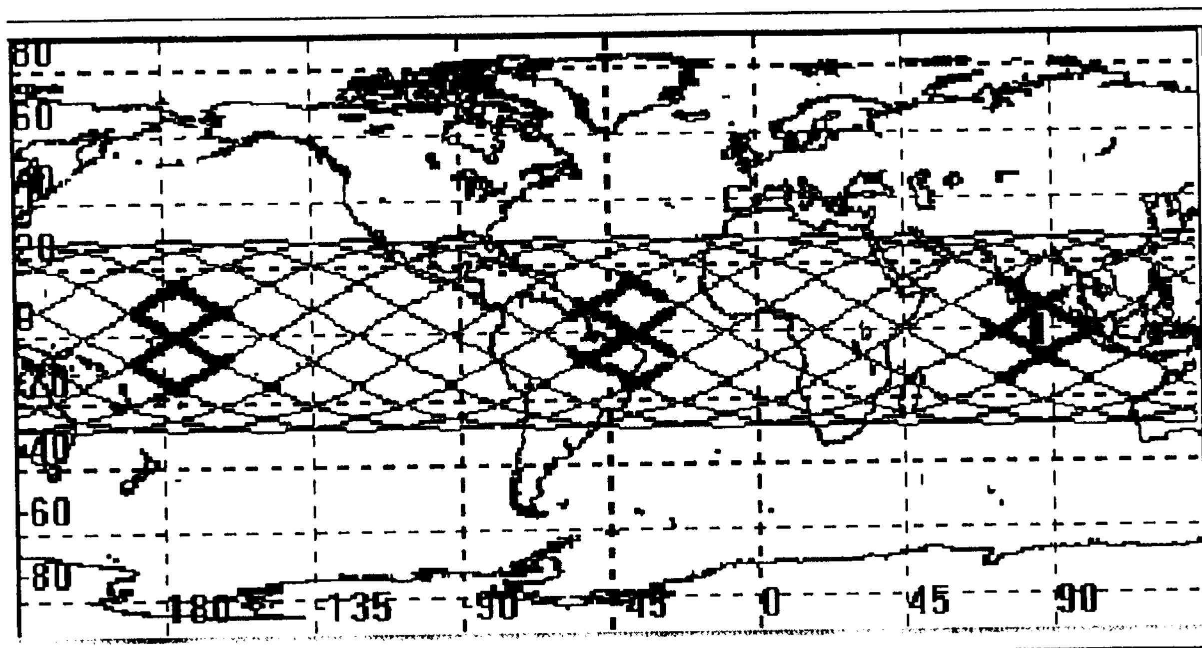
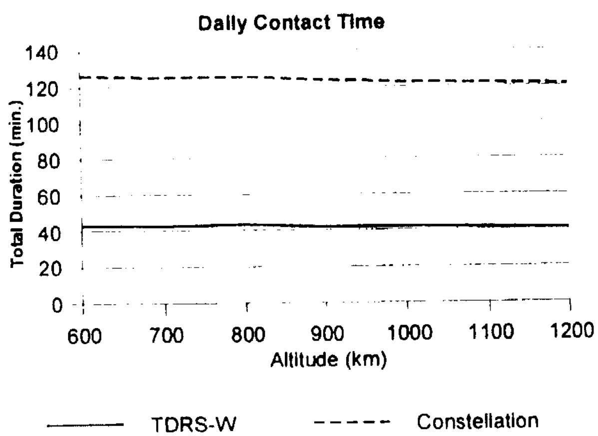
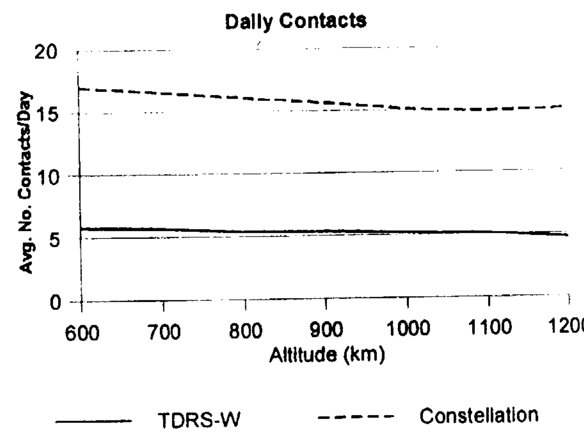
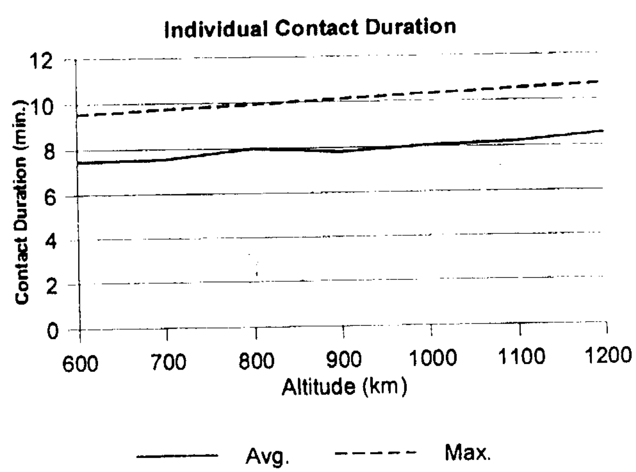



**Figure 1** - Simulated 24-hour ground track for spinning-satellite contact with the Space Network. Highlighted areas along the ground track near the TDRS positions at -174°, -41°, and +85° longitude show times when contact is possible.

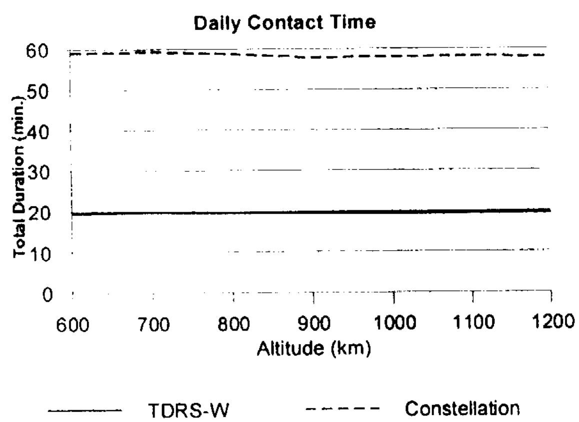
# Orbital Access - 28.5 deg.

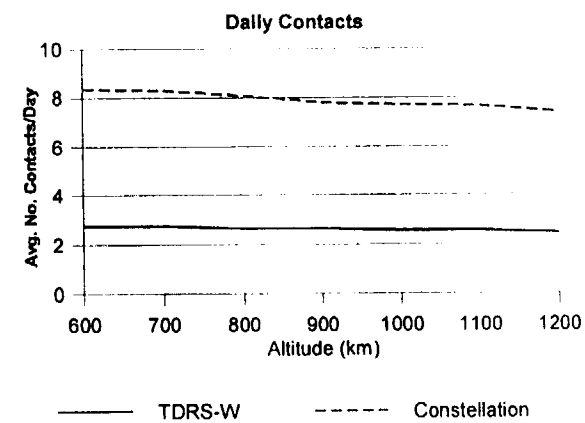


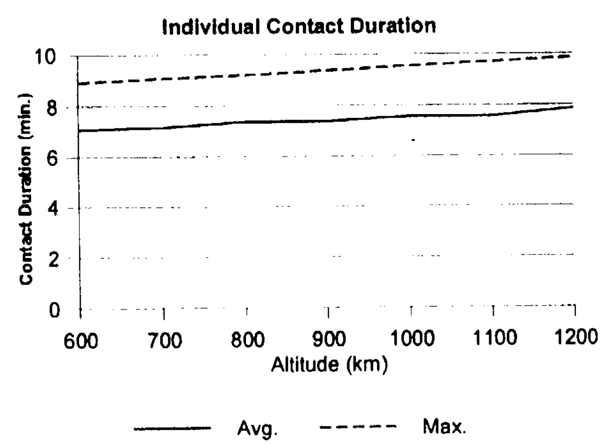



# Orbital Access - sun synch.



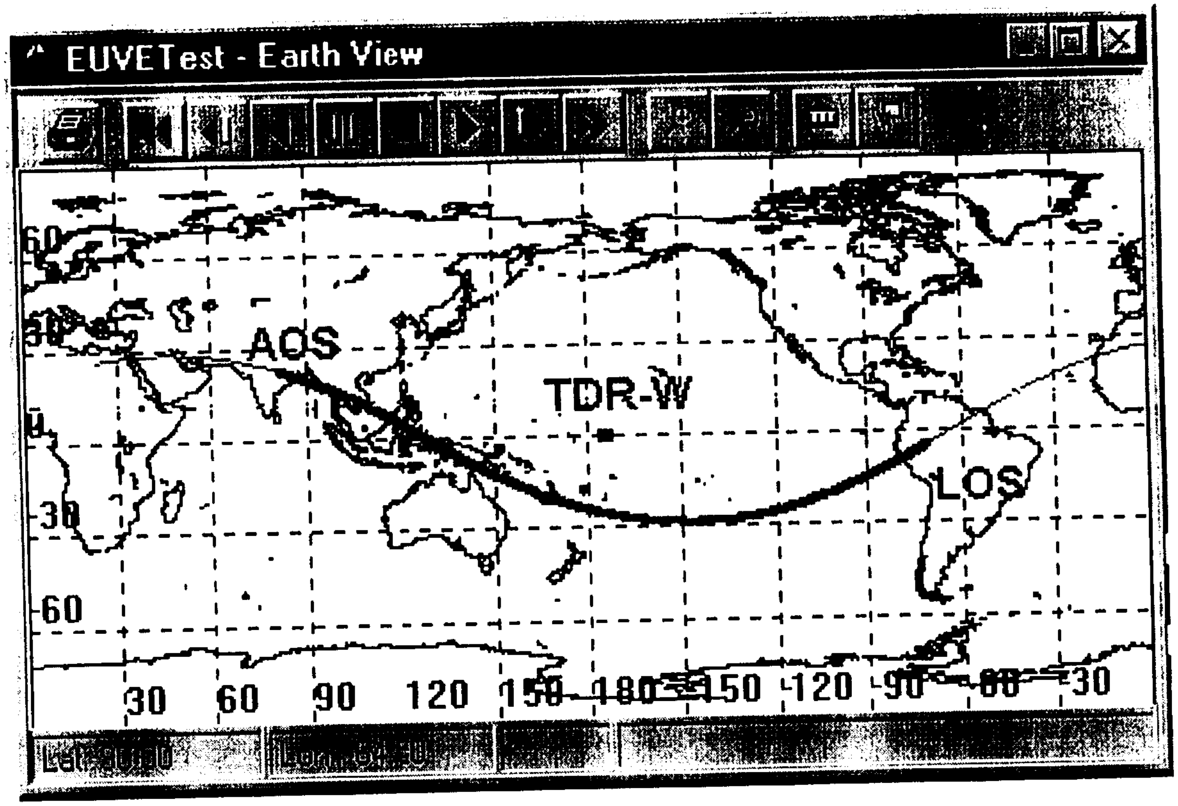



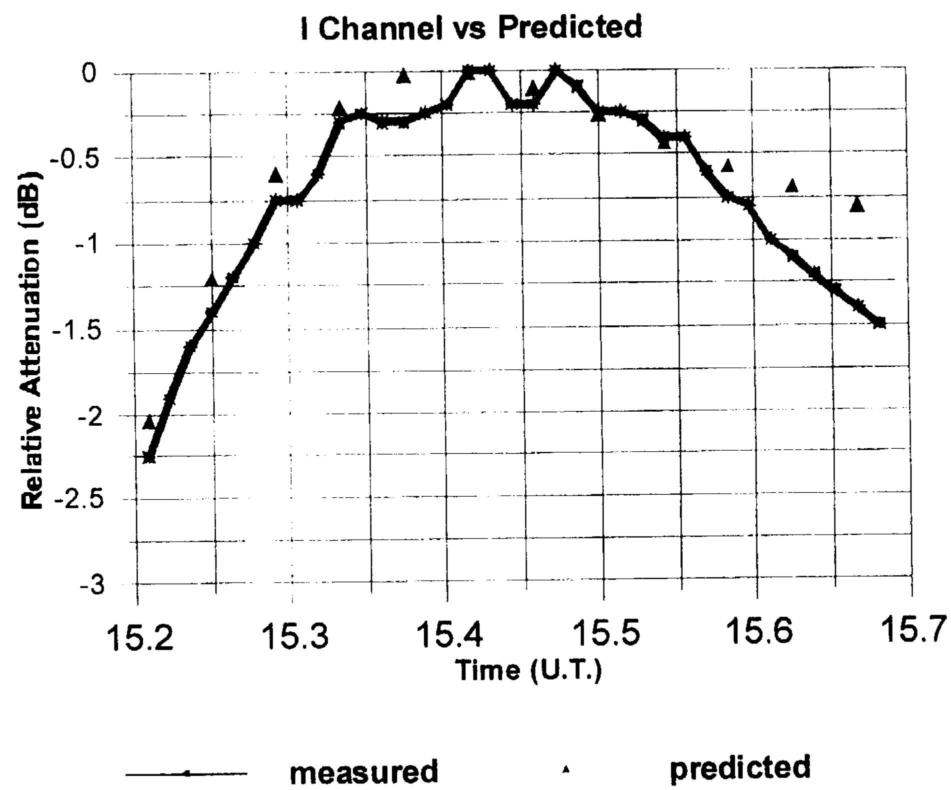
# Current Year Highlights

- EUVE Testing
  - 6 passes used in May 1996
  - found inertially-pointed satellites can remain pointed at a TDRS for up to 50 minutes (30 minutes were observed, 50 minutes simulated)
  - Used STK to simulate passes
    - emulated orbital contact
    - predicted antenna performance due to space loss and pattern gain

# EUVE Testing



# EUVE Testing



# Current Year Highlights

- DAMA Approach
  - Presented baseline approach at the International Telemetering Conference
  - Began work on Doppler tracking methodology in the carrier recovery subsystem
  - Began investigation of how the interface to the WSC beam-forming subsystem might be accomplished

# Current Year Highlights

- RF Testbed
  - began development of requirements for NMSU portion of the system
    - S-Band Transmission
    - helical antenna
    - DG1 Mode 2 transmission
  - began discussions with engineering staff at WSC to insure compatibility of the concept and design

# Plans for Next Year

- Follow-on Spacecraft Testing
  - would like to re-try fixed-antenna pointing scenario with orbiting satellite
  - working with NASA to identify candidate satellite
  - if found, conduct experiment EUVE-type again

# Plans for Next Year

- DAMA Development
  - Complete development of Doppler tracking algorithm
  - Demonstrate its use in the laboratory
  - Complete development of interface requirements to beam forming subsystem at the WSC

# Plans for Next Year

- RF Testbed
  - complete requirements definition and review design with engineers who can critically review
  - begin acquisition and instillation of equipment
  - prepare for testing

# Plans for Next Year

- Hitchhiker Proposal
  - Develop payload concept in detail
  - Select suite of experiments from current NMSU technology development efforts
  - Complete Customer Payload Requirements documentation and submit to NASA

# Hitchhiker Payload

- Plan to develop a suite of experiments to test communications concepts
- Will need to develop requirements for each
  - non-gimbaled antenna pointing
  - DAMA request message
  - passive telemetry via laser communications
  - Turbo Code test

# Future Plans

- DAMA Testing
  - Develop hardware for WSC interface
  - Develop transmitter with "Doppler" offset to carrier
  - Run test signals from NMSU through TDRS to WSC to verify concept

# Future Plans

- RF Testbed
  - Develop capability to test
    - turbo codes
    - bandwidth-efficient modulation
    - small satellite communications
    - packet communications
  - Look for potential industry partners for technology development

# Future Plans

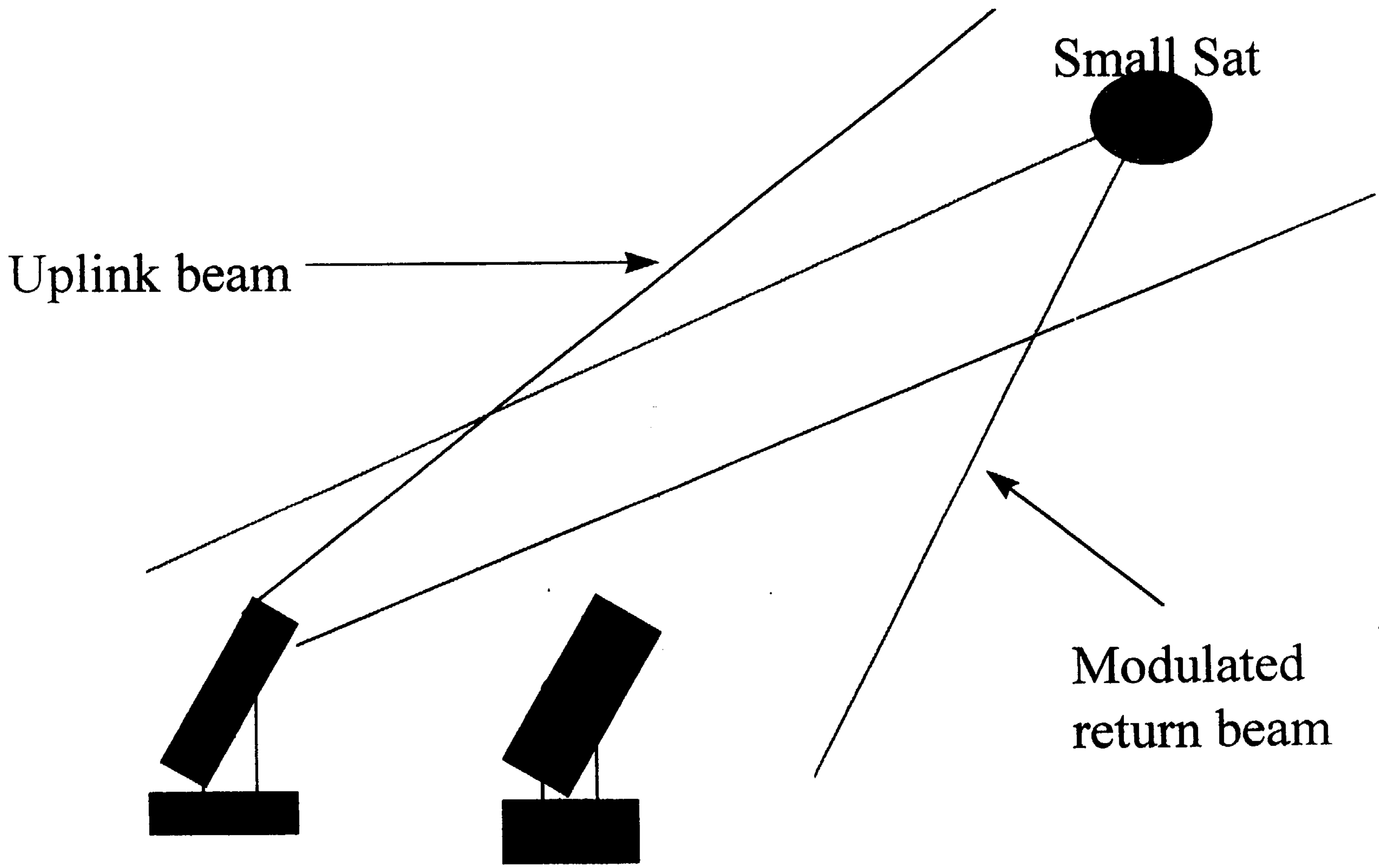
- Hitchhiker Program
  - have proposed project accepted by NASA
  - develop suite of experiments
  - develop partners for technology demonstrations; so far, we are looking at
    - Phillips Laboratory
    - WSMR

# Laser Com Activity

by

T. M. Shay

# LIGHT-WEIGHT LOW DATA RATE OPTICAL COM



# ADVANTAGES

- Very Lightweight and very low power consumption.
- Operation in full daylight will be possible using a FADOF on the ground based receiver
- Relatively low cost ground station

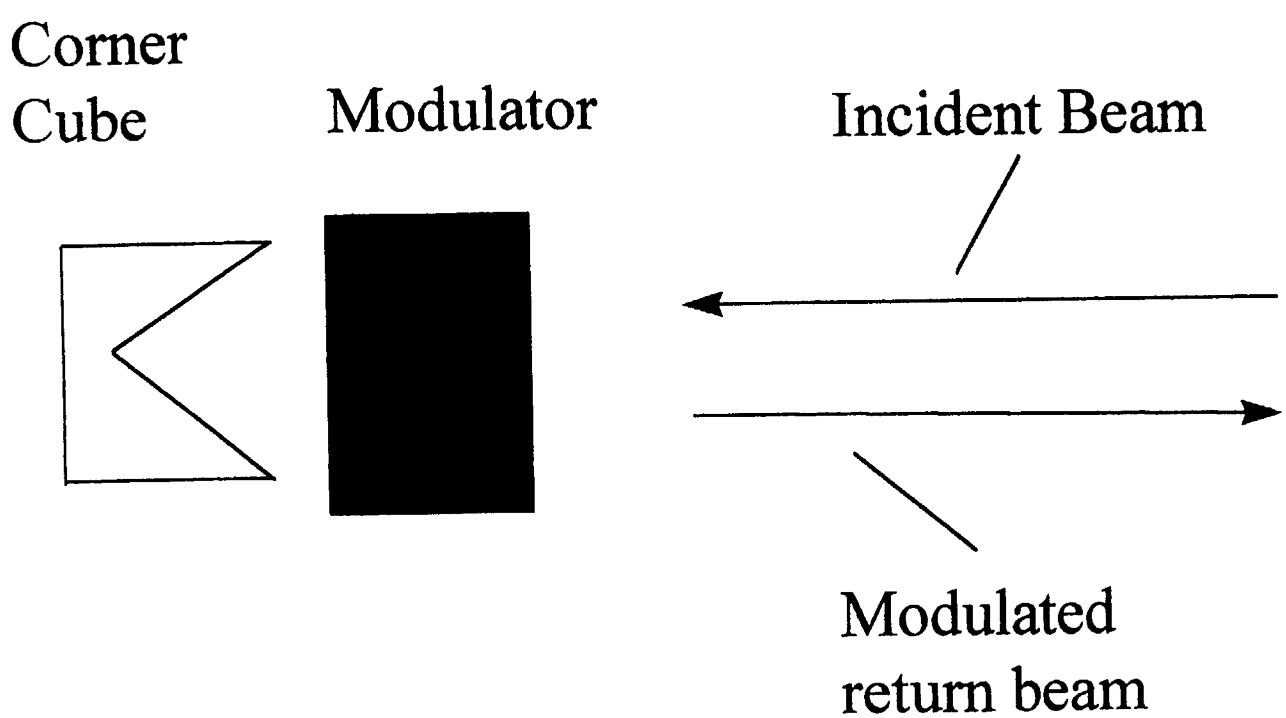
# PLANS FOR NEXT YEAR

- Simple model to estimate system performance and tradeoffs. (Report Sept, 97)
- Design laboratory demonstration unit. (Report April, 98)
- Build and test laboratory demonstration unit. (Report July 1, 98)

# LIGHTWEIGHT LOW DATA RATE OPTICAL COM POSSIBILITIES

| Data Rate kb/s | Receiver Diameter | Modulator Size | Laser Power mW | Comments |
|---|---|---|---|---|
| 10 | 1.8 m | 4” x 4” | 150 | Demonstration System Using Existing Tracking Scopes |
| 1 | 1.8 m | 4” x 4” | 45 | |
| 10 | 16 in | 8” x 10” | 100 | Potential Fielded System |
| 1 | 16 in | 8” x 10” | 40 | |

# Satellite Components



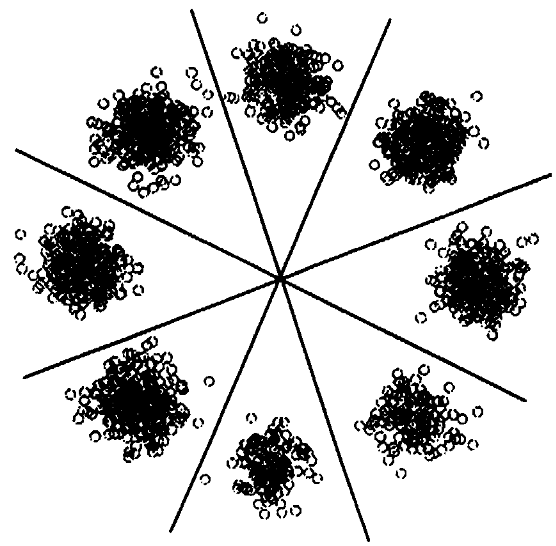
# LONG TERM PLAN

- Year I. Model performance and lab test.
- Year II. Perform field experiment (1/2 km)
- Year III. Build and test satellite. (Needs additional funding)
- Year IV. Fly satellite and test satellite laser com. (Needs additional funding)

# PROGRESS THIS YEAR

- Fast optical logic model.
  - Quantum Mechanical Theory Development on schedule.
- Stark Anomalous Dispersion Optical Filter.
  - Signal Oscillator Designed and testing has begun. This is also on schedule.
- This work will be completed this year.

# 8PSK SIGNALING OVER NON-LINEAR SATELLITE CHANNELS



Sheila Horan
Rubén Caballero, Jianping Tao, Josua Purba

(supported by a grant from NASA #NAG 5-1491)

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Space & Telecommunications Center

3/10/97

# PRESENTATION

1- Introduction

2- Approach

3- SPW Simulations
- End-to-End Functional System Diagram and Description

4- Results for 8PSK Modulation
- Power Containment and Spurious Emissions
- End-to-End System Performance
- Non-Constant Envelope

5- Conclusions & Further Work

# (2)- APPROACH (cont.)

- Software used: - SPW on Sun Sparc 10 Unix Station
  - Matlab on PC (Windows) and Unix
- Block Diagram Created on SPW to perform simulations
- Measurements:

1 - Measure and Plot: Power Spectral Density PSD
( calculate Utilization Ratio, at -50dB point)
2 - Measure Symbol Error Rate (BER)

- BER plotted as function of symbol SNR (Eb/No)
- Baseband Filter Optimization:
BT product selected such that filter ISI Loss < 0.4dB at $10^{-3}$

3 - Non-Constant Envelope Mesurements
- plot Average Symbol Variance vs. Bandwidth

# (1) - INTRODUCTION

- SFCG-12 (Australia , Nov 92) requested the study and comparison (CCSDS RF) of various modulation schemes in:

  - BW needed;
  - power efficiency;
  - spurious emissions; and
  - interference susceptibility.

- Why this study?

  - frequency bands are becoming more and more congested; and
  - space agencies are under constant pressure to reduce costs:
    - power efficiency.

- 3 Phases

  Phase I : BW utilization of various modulation schemes
  Phase II : Effect of Spectrum Shaping
  Phase III: End-to-End Performance with different Modulation Schemes

# *(3) - SPW SIMULATIONS*
# *8PSK Over Non-Linear Channel*

SPW Simulation Variables:

- Bit rate = $R_B$ = 1 bps ($R_s$ = Symbol Rate = (1/3) symbol/s ;
- Sample Rate = fs = 16 samples/sec;
- Data: NRZ-L;
- Carrier Frequency = 0 Hz (Baseband Simulations);

Transmitting System:

- Data Generator: Ideal and Non-Ideal Data;
  - data assymetry = 2%;
  - data imbalance = 0.45;
- Baseband Filters do not include resistive and reactive losses;
- Power Amplifier based on:
  - ESA 10-watt Solid State Amplifier (SSPA);

# *(3) - SPW SIMULATIONS*
# *8PSK Over Non-Linear Channel (cont.)*

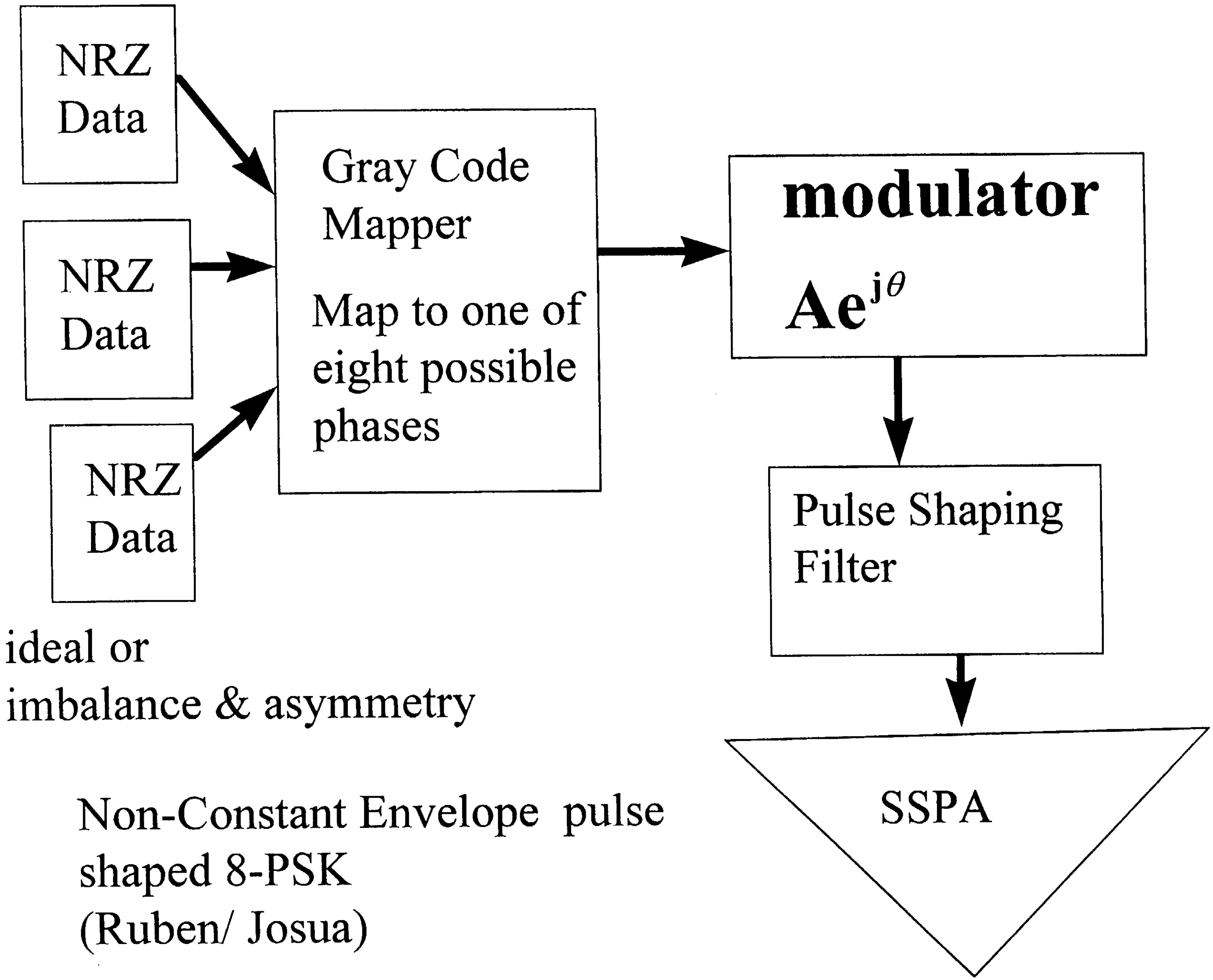
<u>Receiving System:</u>

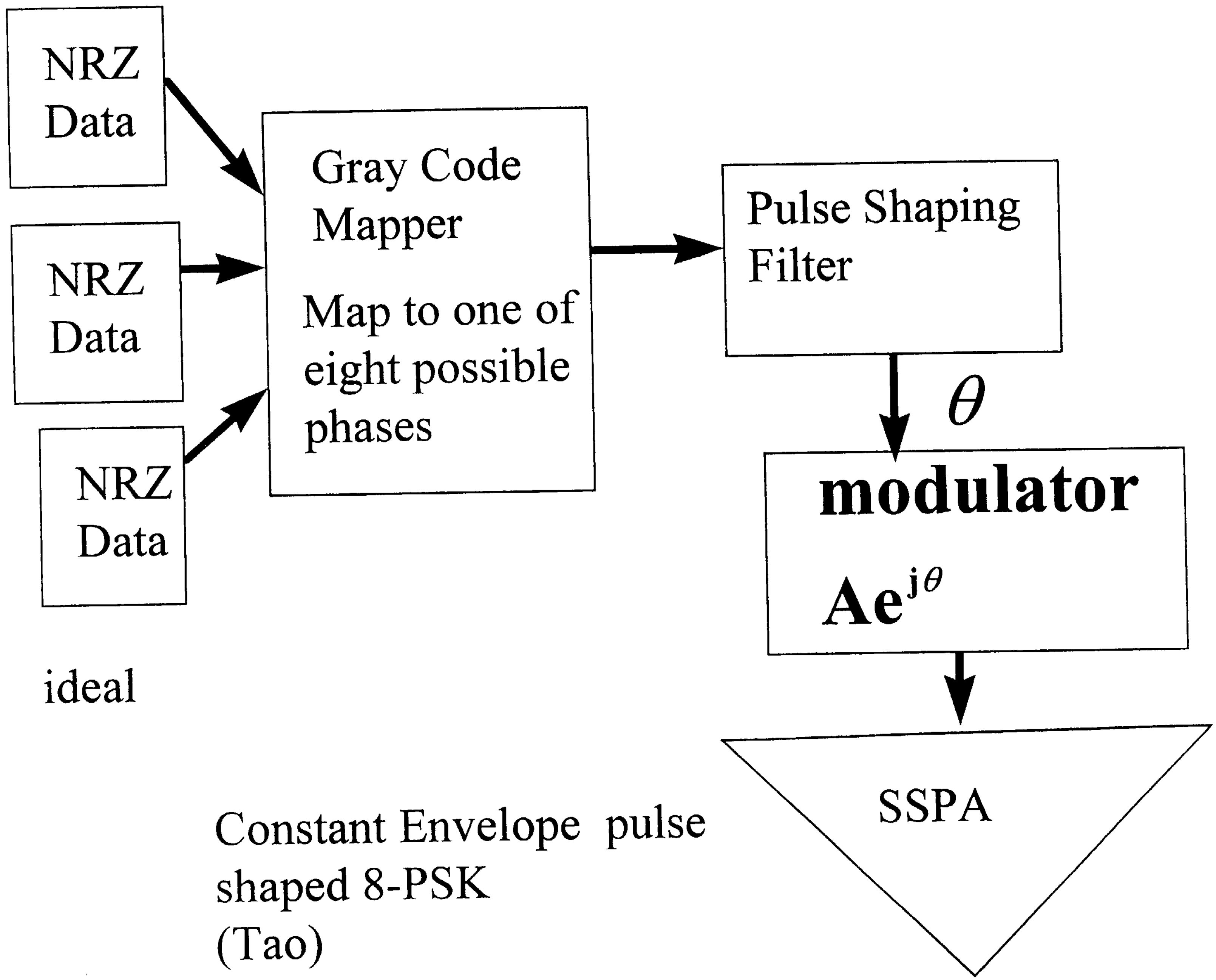
- Matched Filter: Sliding Integrator;
  SRRC matched filter used for non-constant envelope
- Delay and Phase Meter (Synchronization); and
- Error Rate Estimator.

<u>Baseband Filters:</u>

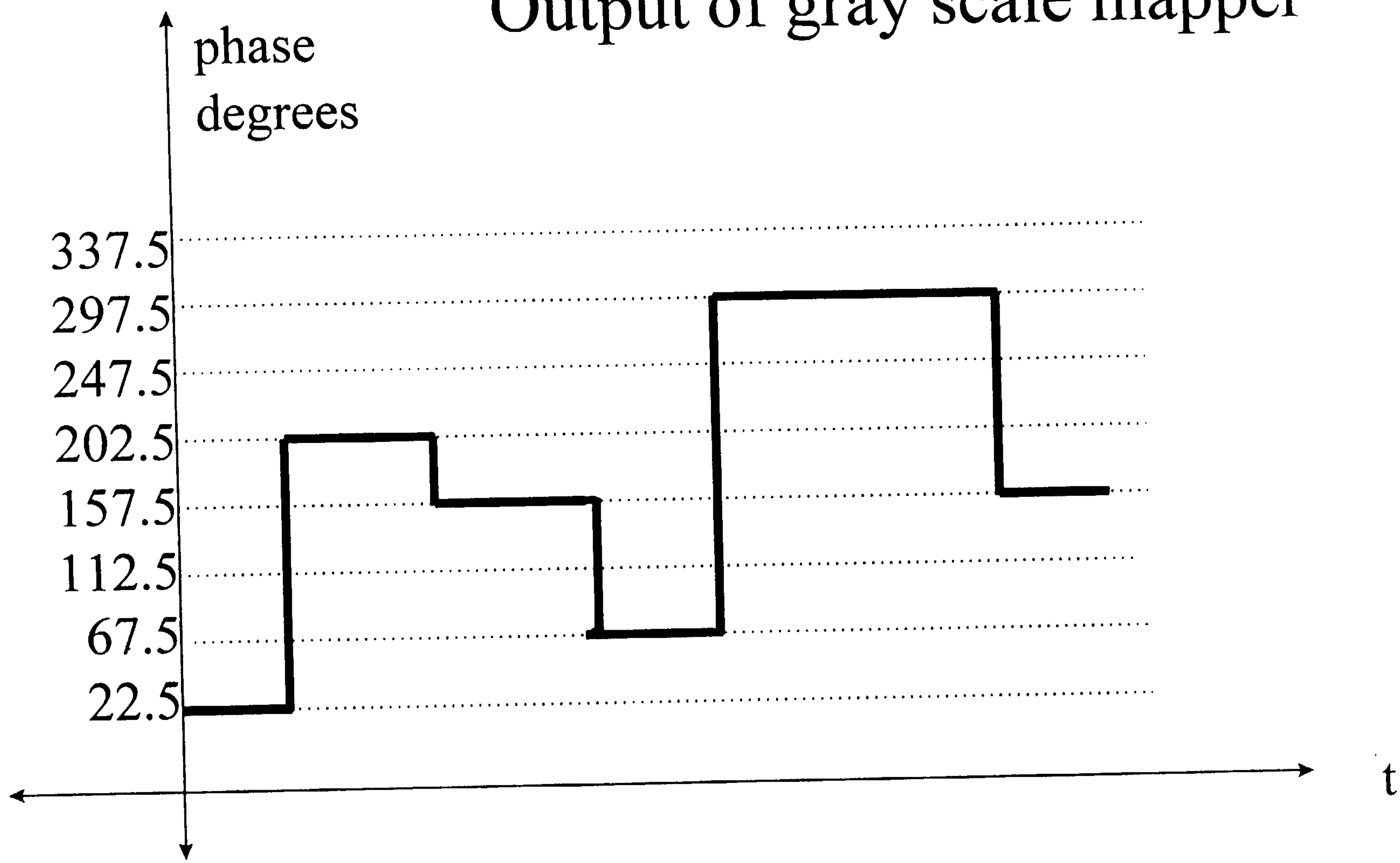
From Phase II :

- Butterworth 5th Order (BT=1,2,3);
- Bessel 3rd Order(BT=1,2,3);
- Square Root Raised Cosine (SRRC)
  $\alpha = 1$ and 256 taps;


NRZ Data
NRZ Data
NRZ Data
Gray Code Mapper
Map to one of eight possible phases
modulator
$Ae^{j\theta}$
Pulse Shaping Filter
SSPA
ideal or
imbalance & asymmetry
Non-Constant Envelope pulse shaped 8-PSK
(Ruben/ Josua)

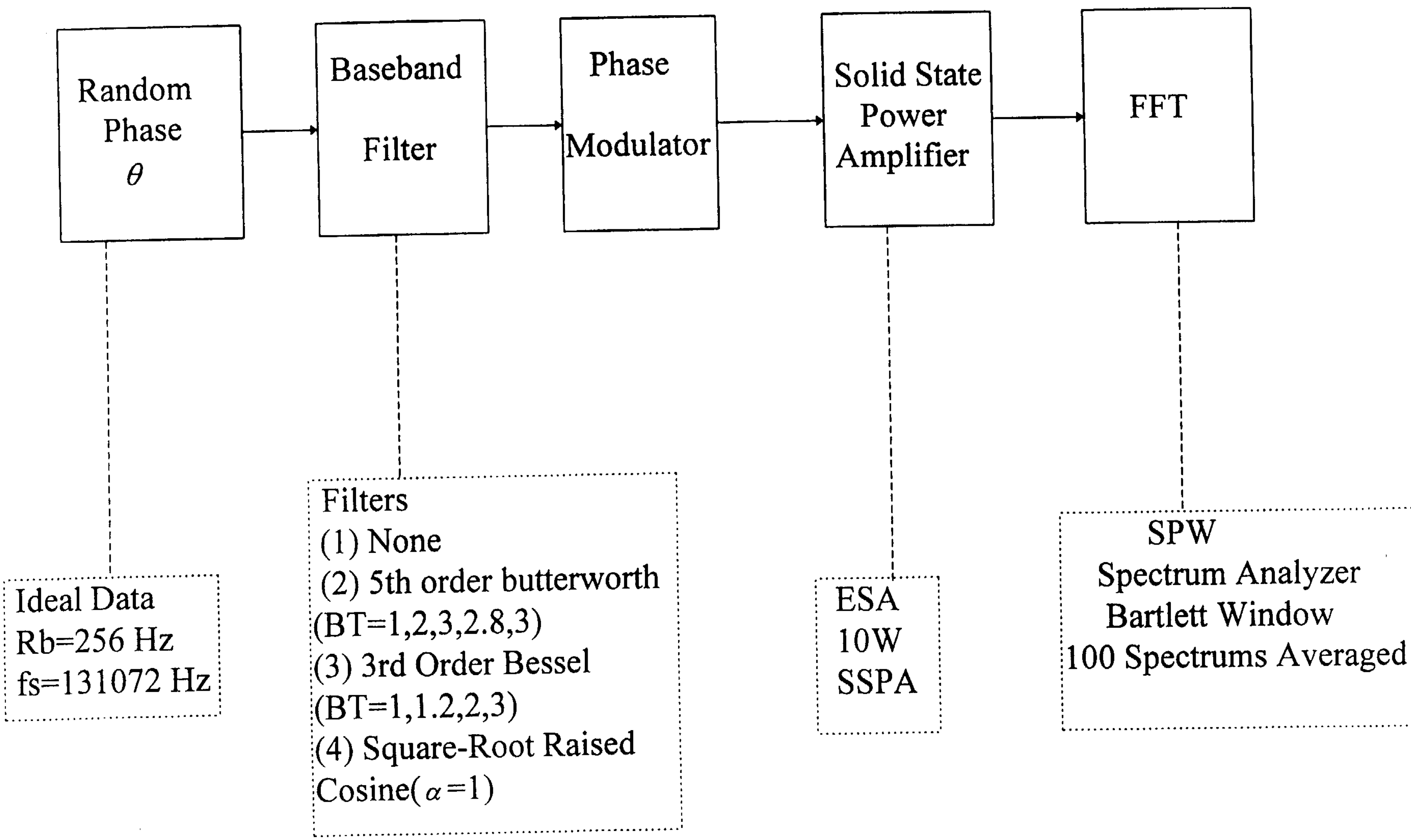

NRZ Data
NRZ Data
NRZ Data
Gray Code Mapper
Map to one of eight possible phases
Pulse Shaping Filter
θ
modulator
Ae^{jθ}
SSPA
ideal
Constant Envelope pulse shaped 8-PSK
(Tao)

# Output of gray scale mapper

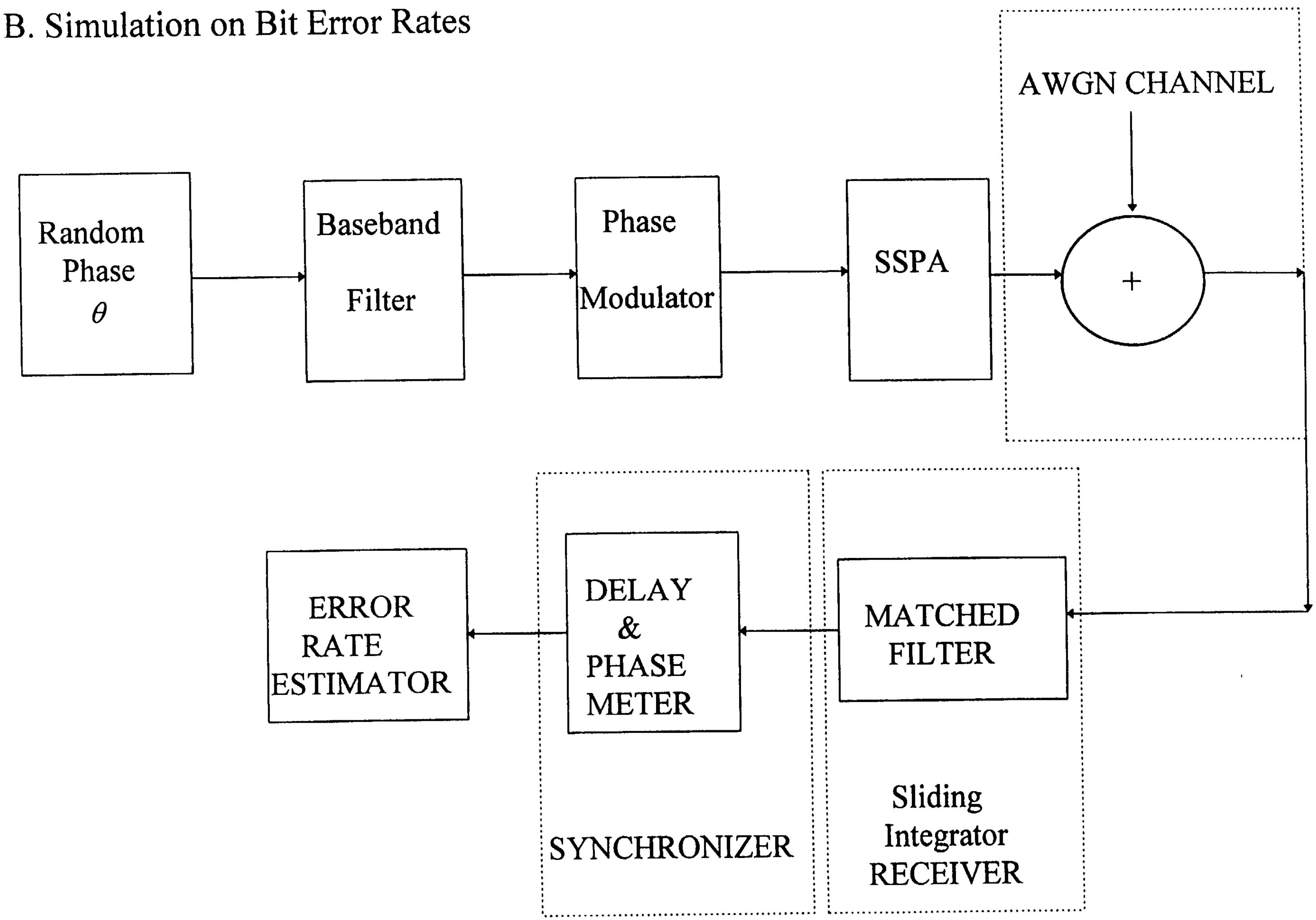


## . 8PSK EFFICIENT MODULATION STUDY OVERVIEW

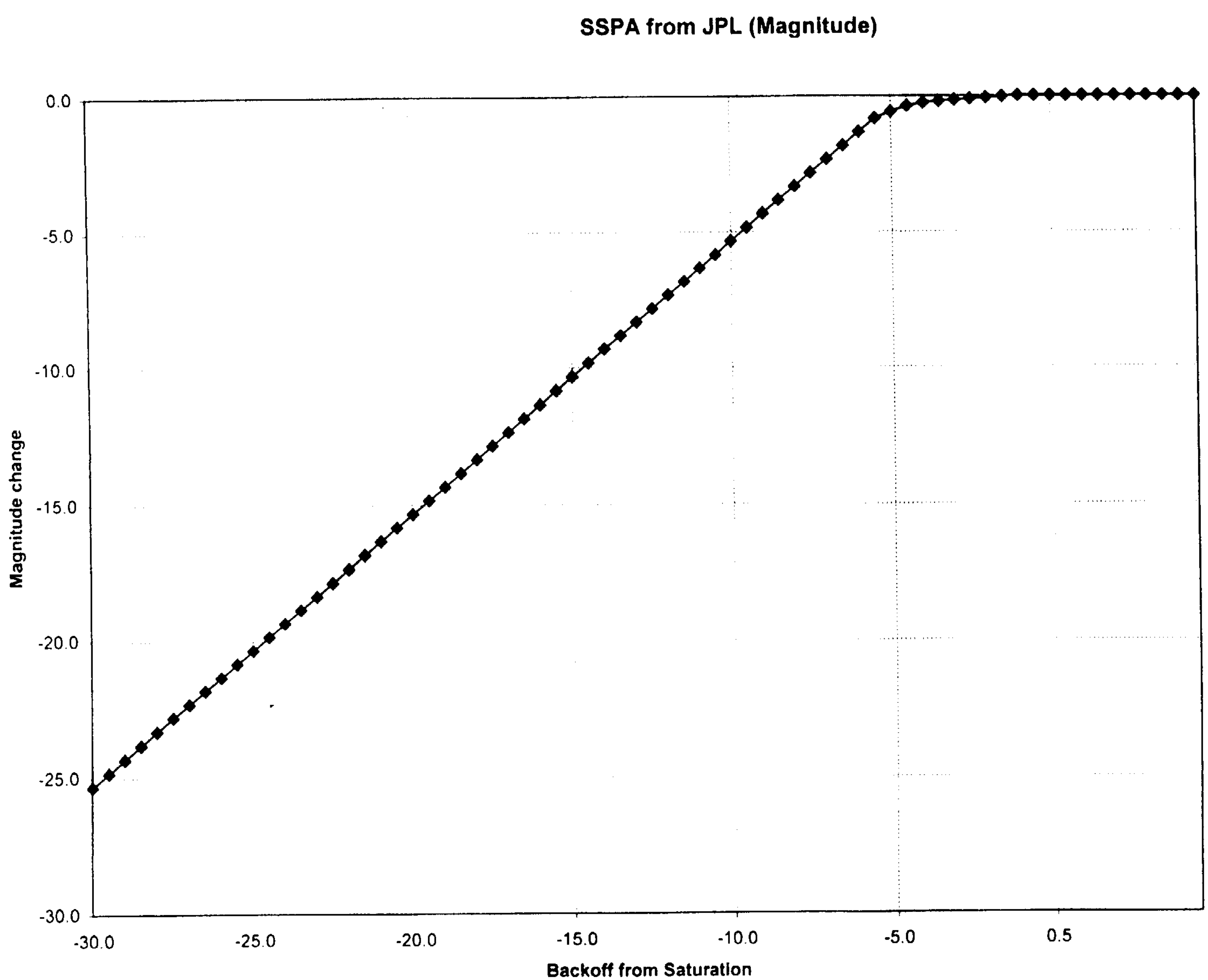
A. Spectrum Analysis

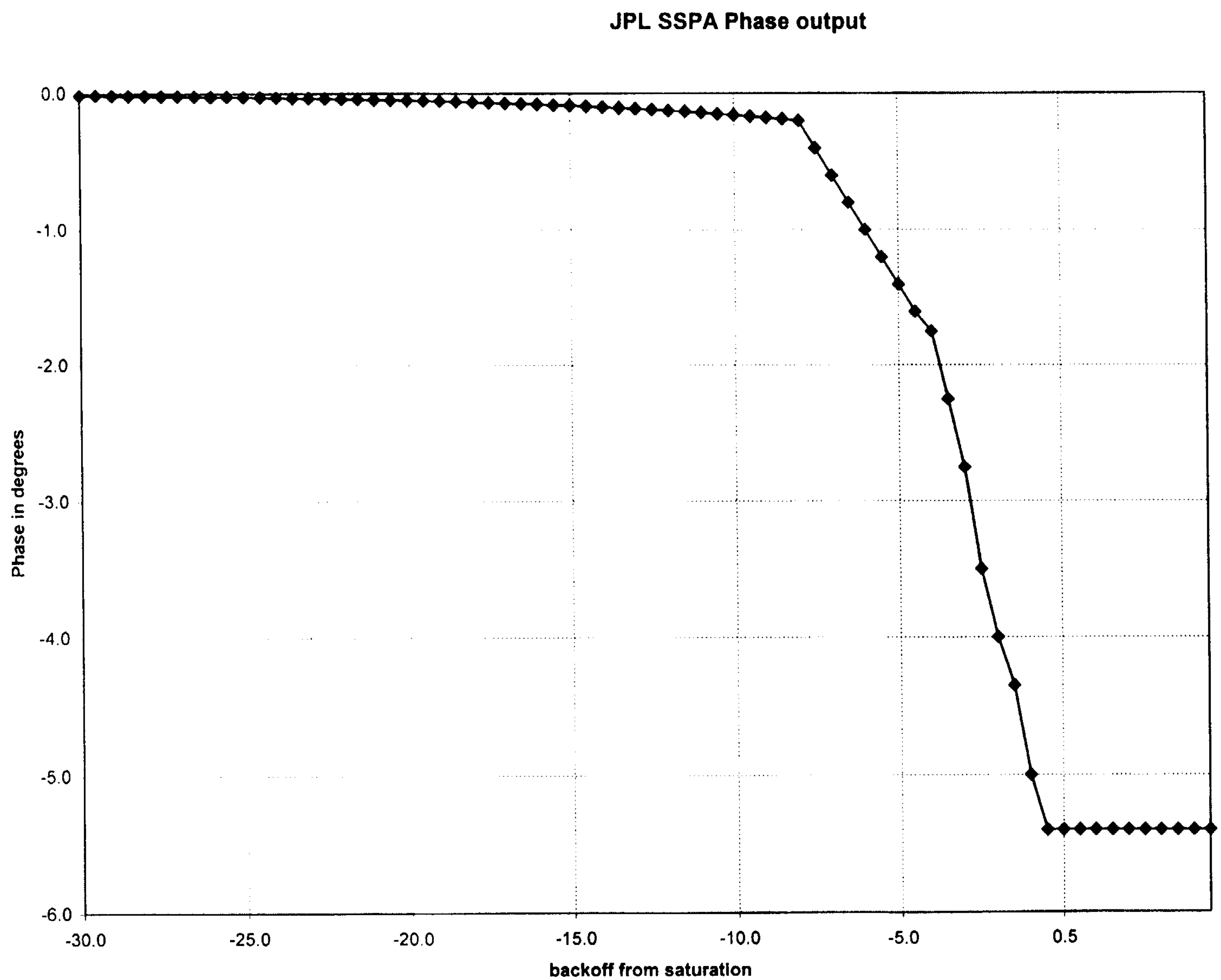


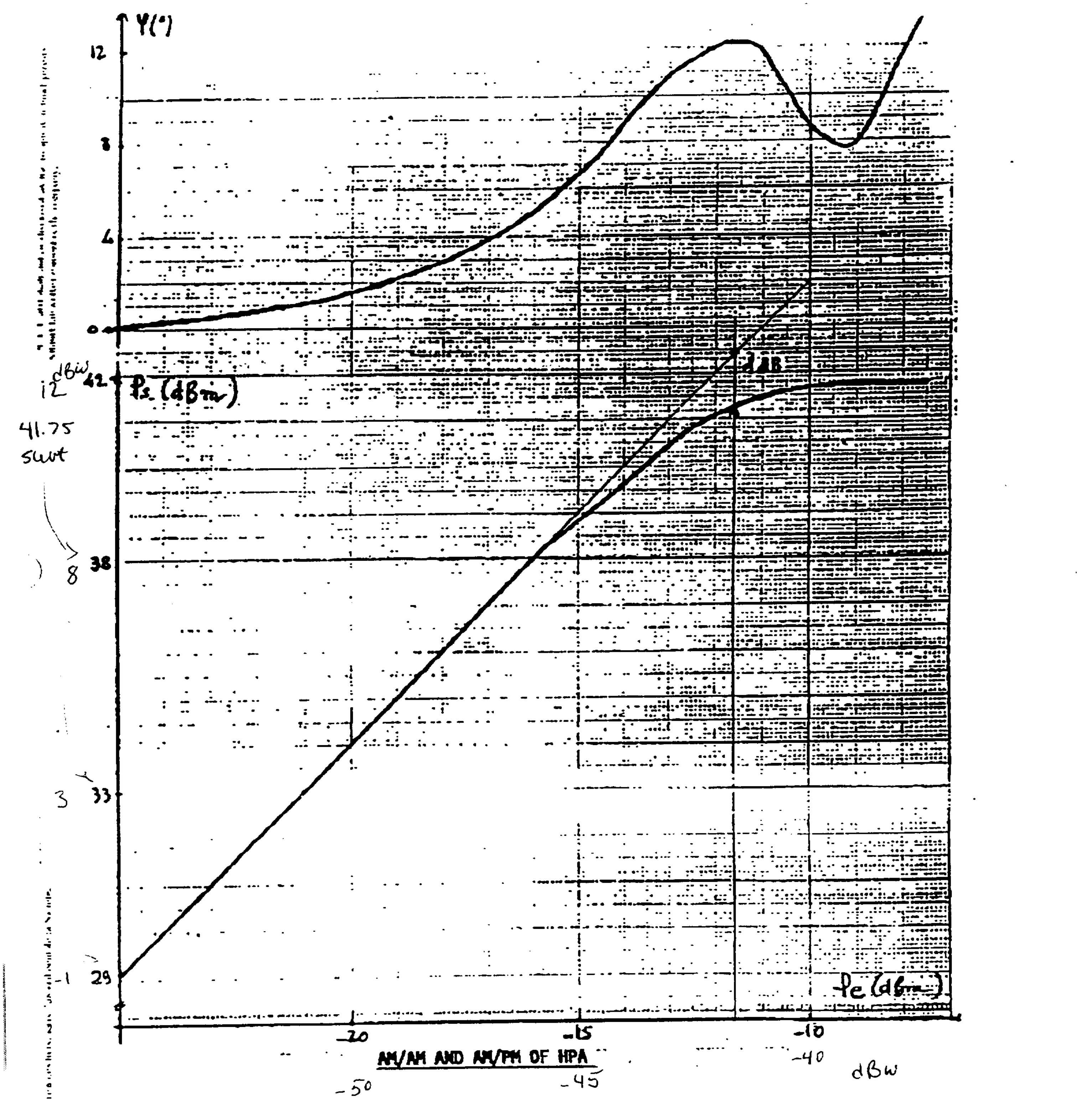
B. Simulation on Bit Error Rates



sspa3.ascsig Chart 1




JPL SSPA Phase output
Phase in degrees
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
-30.0
-25.0
-20.0
-15.0
-10.0
-5.0
0.5
backoff from saturation


Ψ(°)
12
8
4
0
42
$P_s$ (dBm)
12 dBW
41.75
sat
38
8
33
3
29
-1
1dB
$P_e$ (dBm)
-20
-15
-10
AM/AM AND AM/PM OF HPA
-50
-45
-40
dBW

# (4) - RESULTS FOR 8PSK
## 8PSK Over Non-Linear Channel



Power Containment and Spurious Emissions

- PSD plots
- Band Utilization Ratio
    . establishes user spacing based upon modulation characteristics
    . sideband attenuation avoids interference to adjacent users

$$\rho = \frac{\text{number of s/c with filtering accomodated in freq. band}}{\text{number of s/c without filtering accomodated in freq. band}}$$

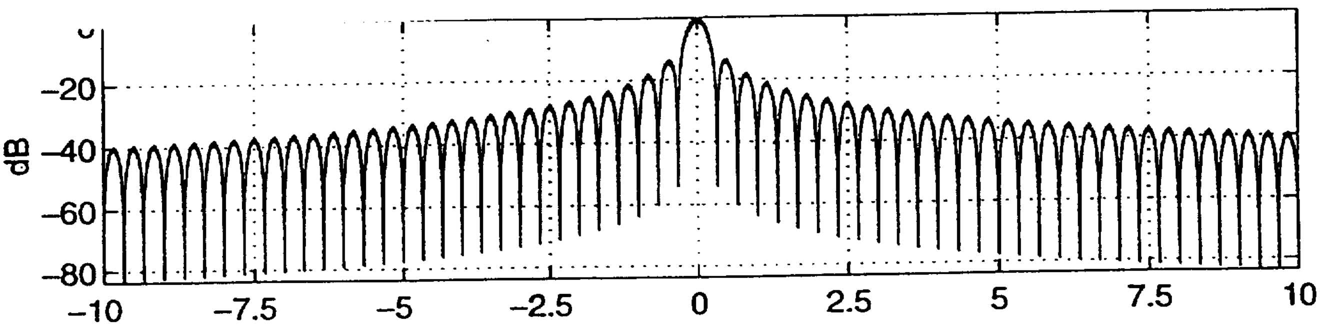
End-to-End Performance:

- BER plotted as function of symbol SNR (Eb/No)

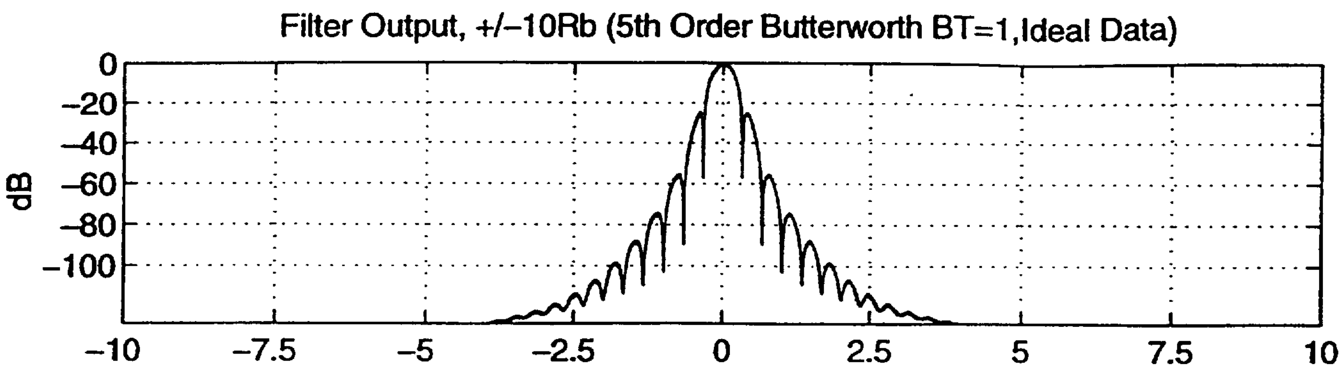
Non-Constant Envelope

- Average Symbol Variance vs. Bandwith

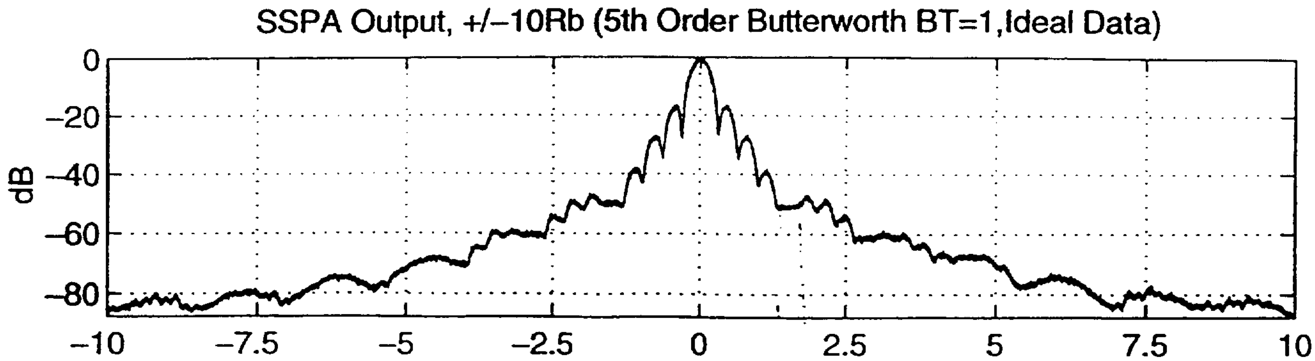
# Power Spectra Plots
# Non-constant envelope 8 PSK




Original Data

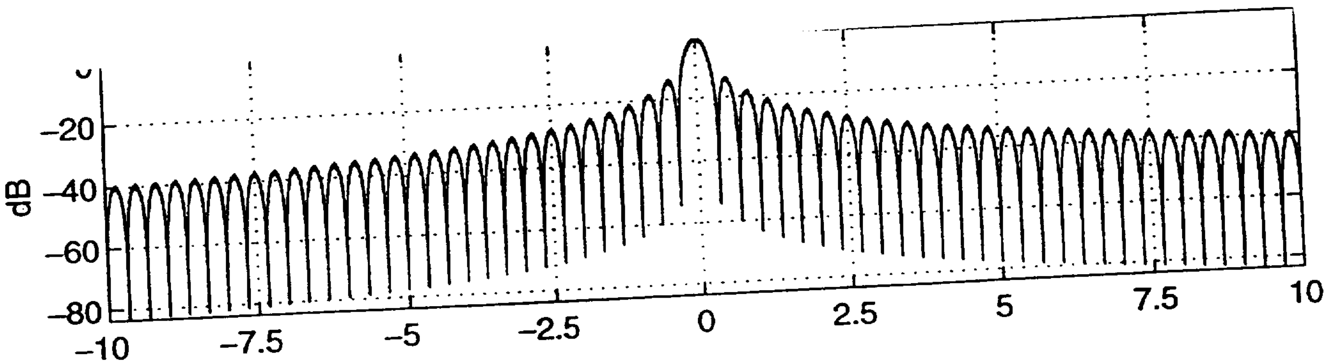



Filter Output from the $5^{th}$ Order Butterworth Filter, BT=1



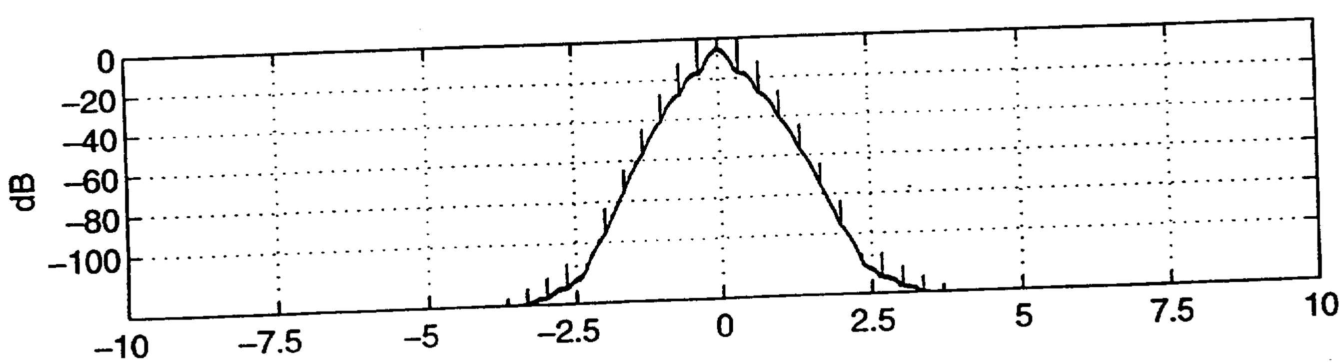

Output from the SSPA after filtering the data

# Power Spectra Plots
# Constant envelope 8 PSK



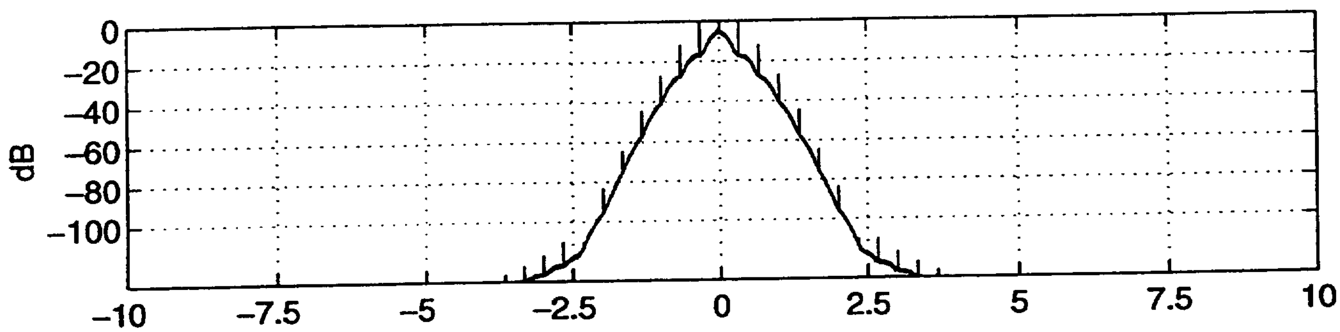

Original Data

Filter Output from the $5^{th}$ Order Butterworth Filter, BT=1

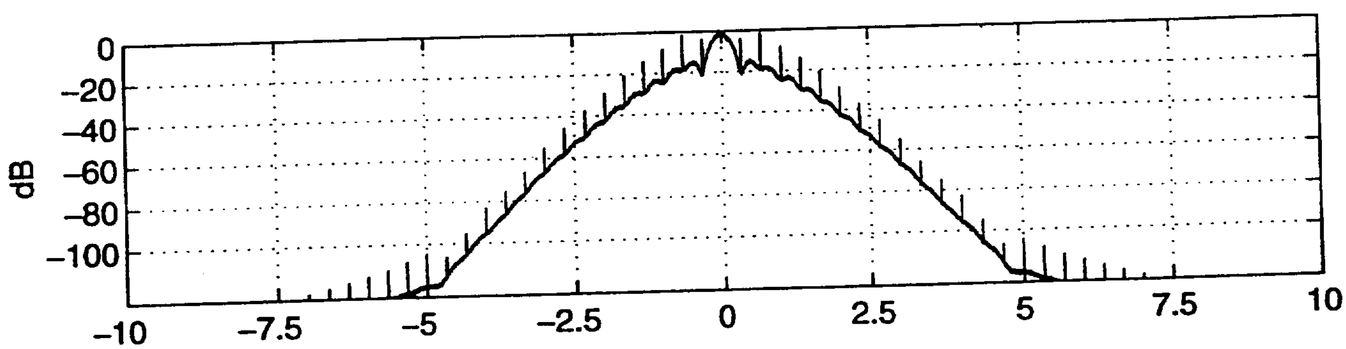



Output from the SSPA after filtering the data

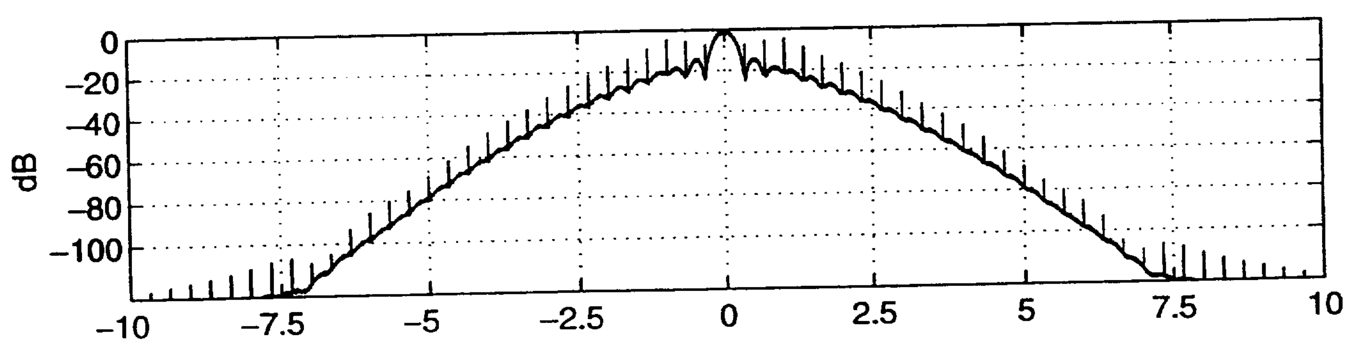
# SSPA Power Spectra Plots
# Constant envelope 8 PSK




Butterworth Filter, BT=1

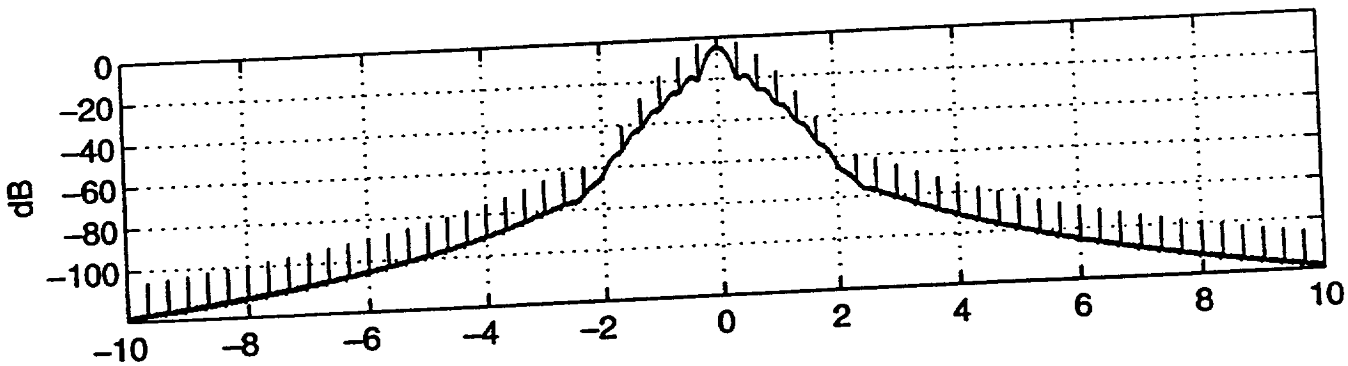



5th Order Butterworth Filter, BT=2

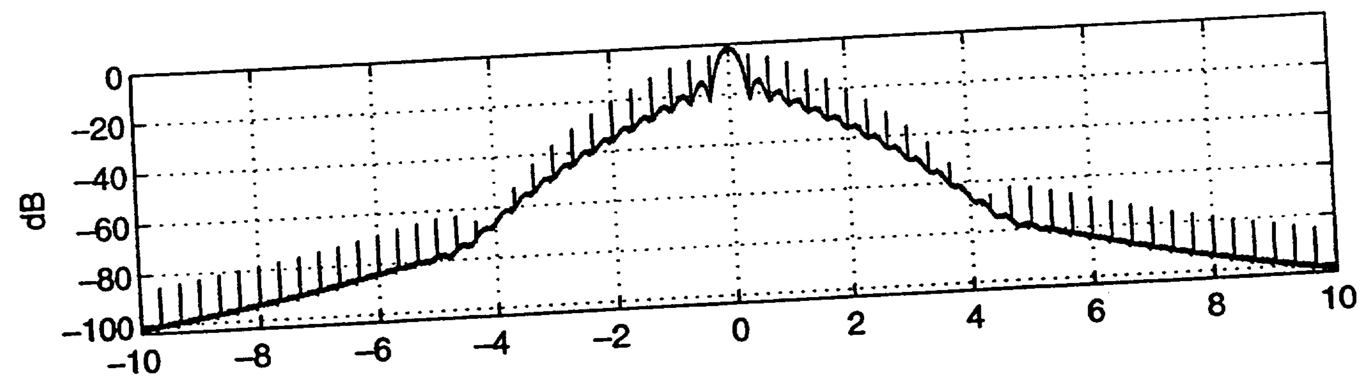



5th Order Butterworth Filter, BT=3

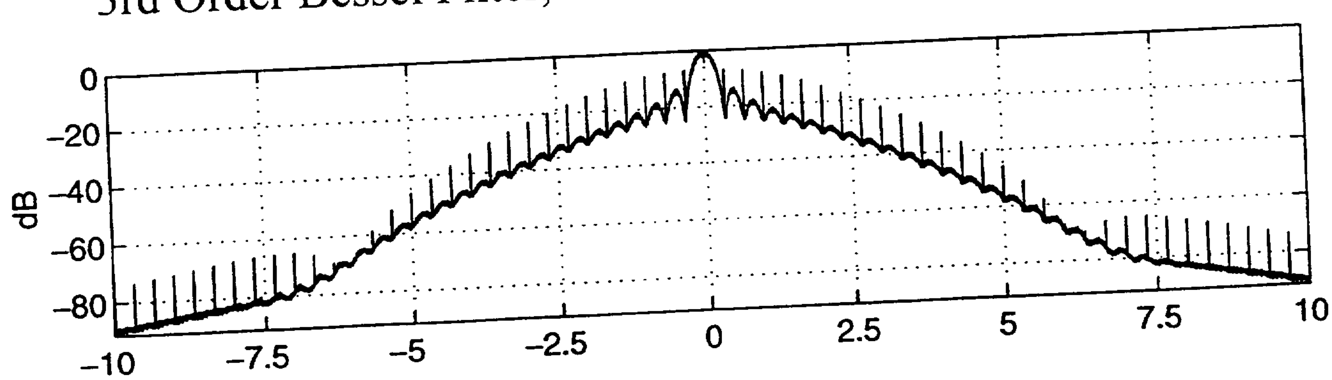
# SSPA Power Spectra Plots
# Constant envelope 8 PSK




3rd Order Bessel Filter, BT=1

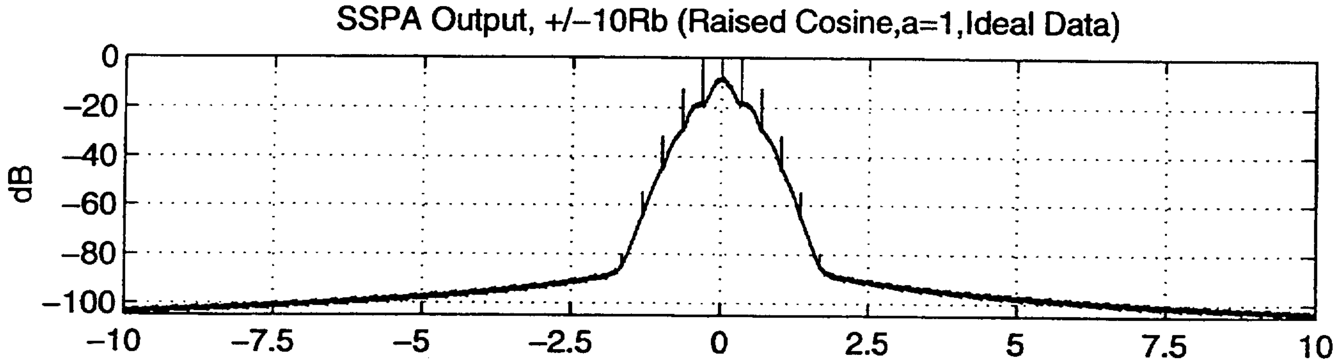



3rd Order Bessel Filter, BT=2



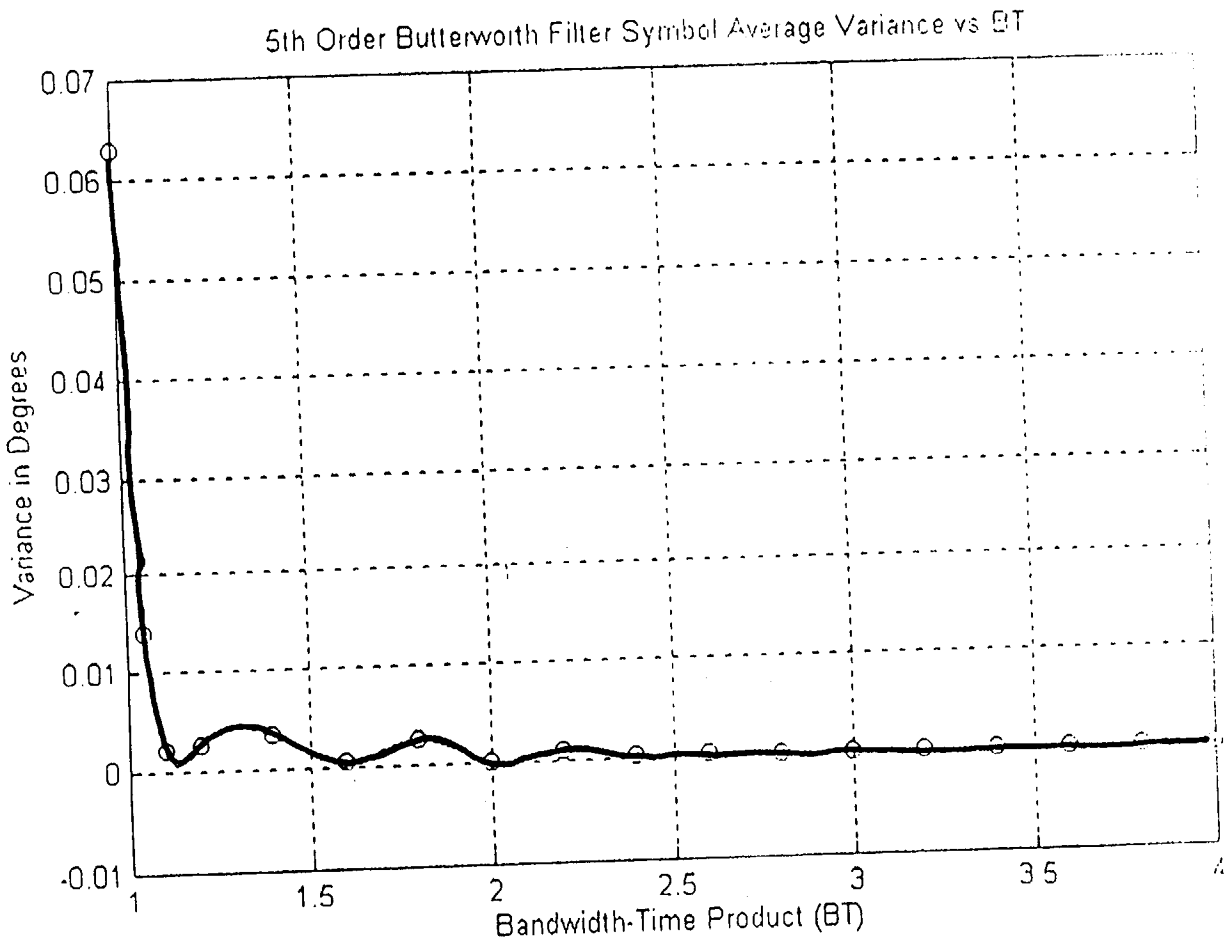

3rd Order Bessel Filter, BT=3

# SSPA Power Spectra Plots
# Constant envelope 8 PSK

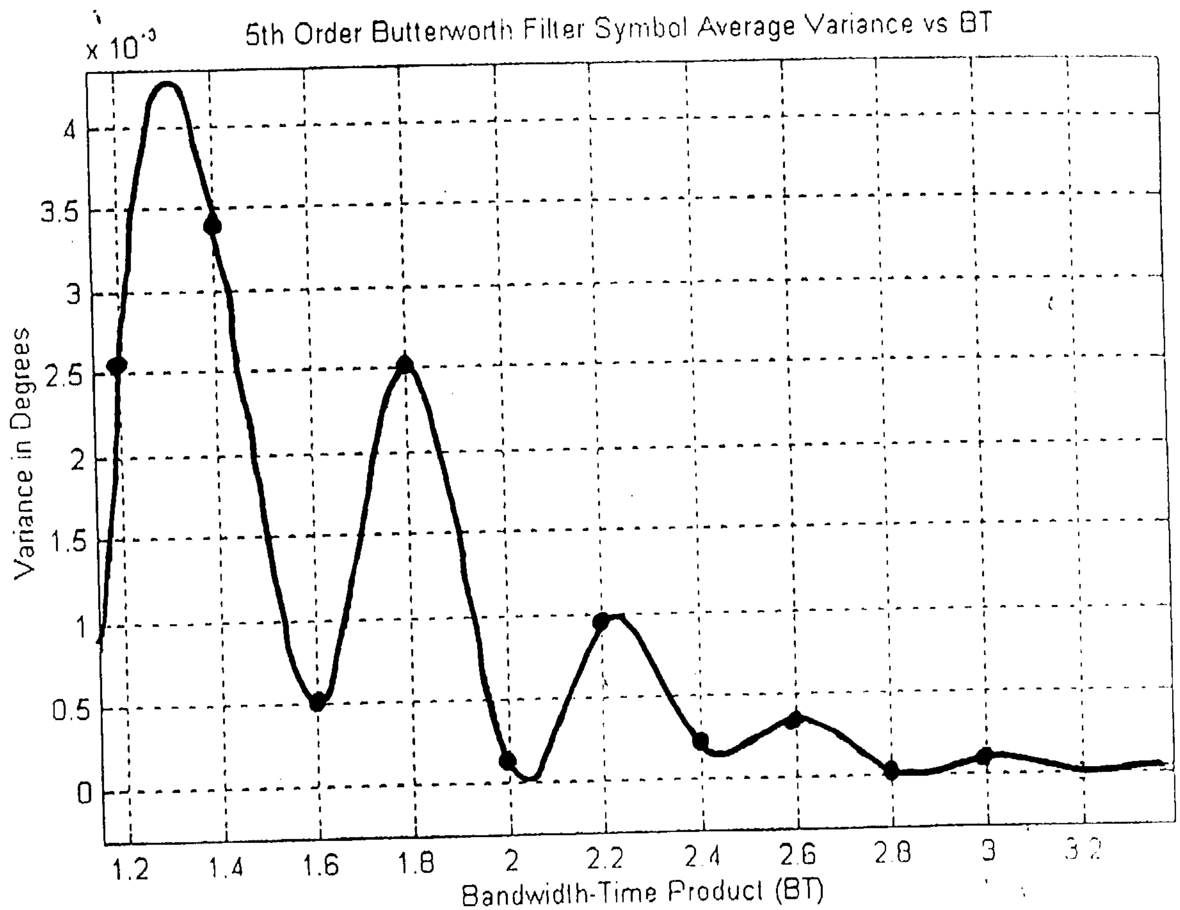



Square Root Rasied Cosine Filter, roll off factor, a=1

# RESULTS FOR 8PSK
## 8PSK Over Non-Linear Channel

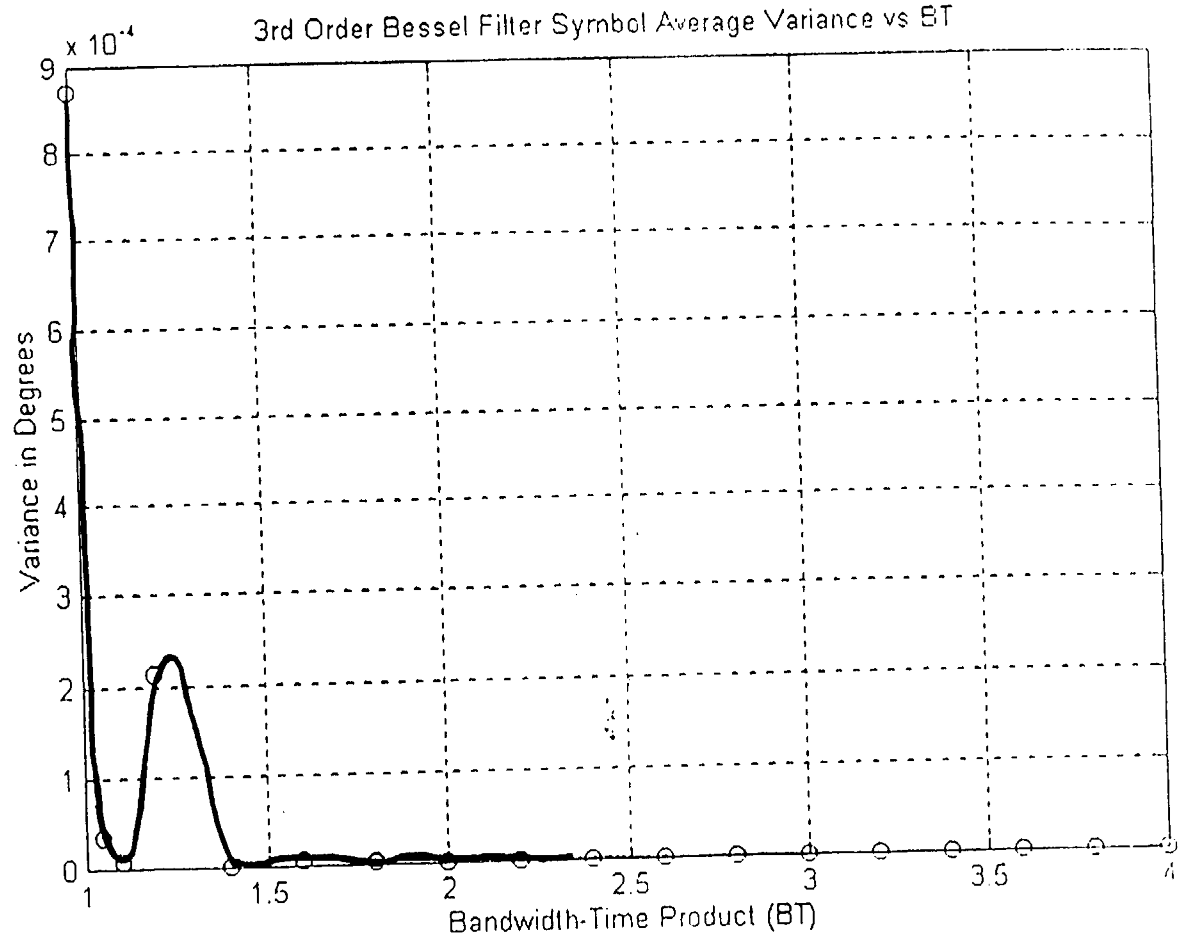


# RESULTS FOR 8PSK
## 8PSK Over Non-Linear Channel



# *RESULTS FOR 8PSK*

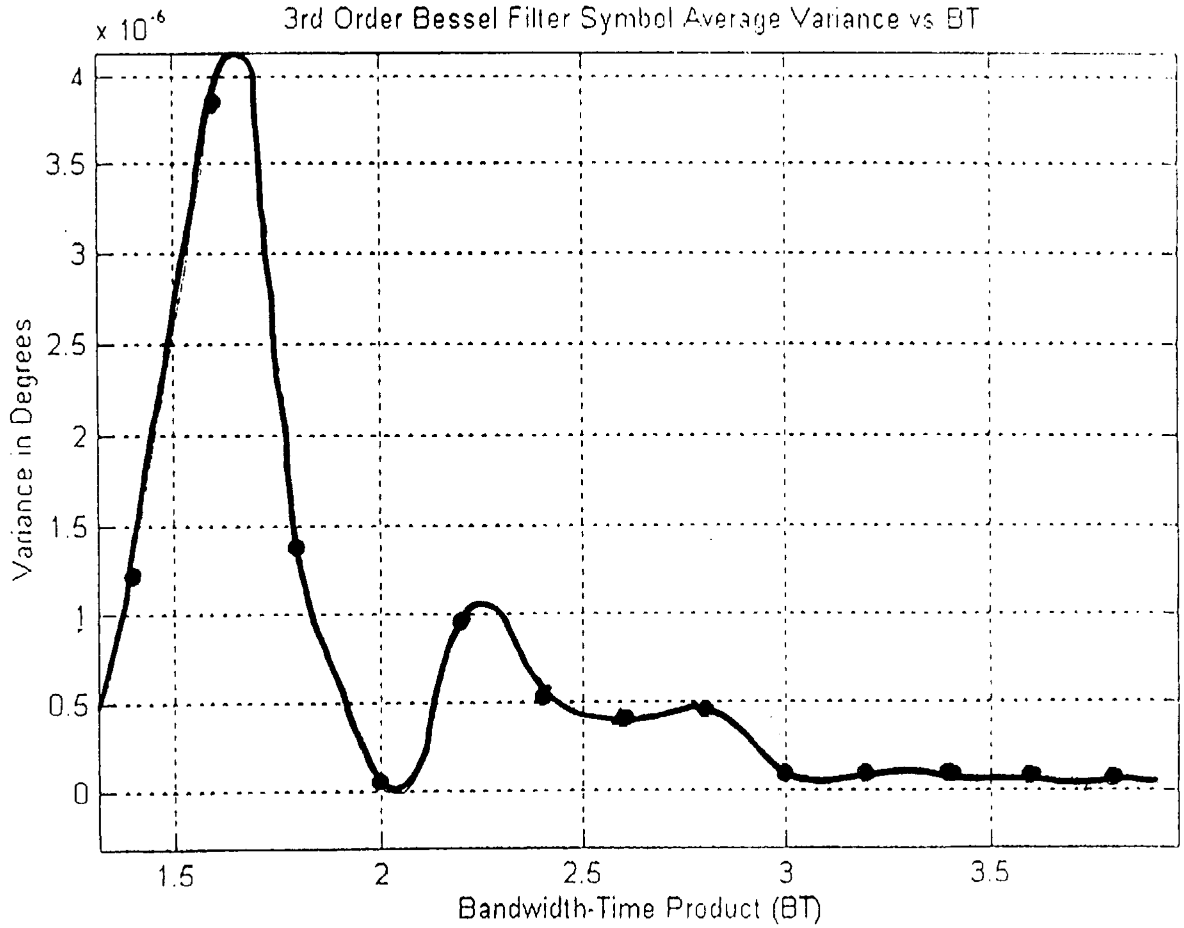
## *8PSK Over Non-Linear Channel*




3rd Order Bessel Filter: Average Symbol Variance vs BT

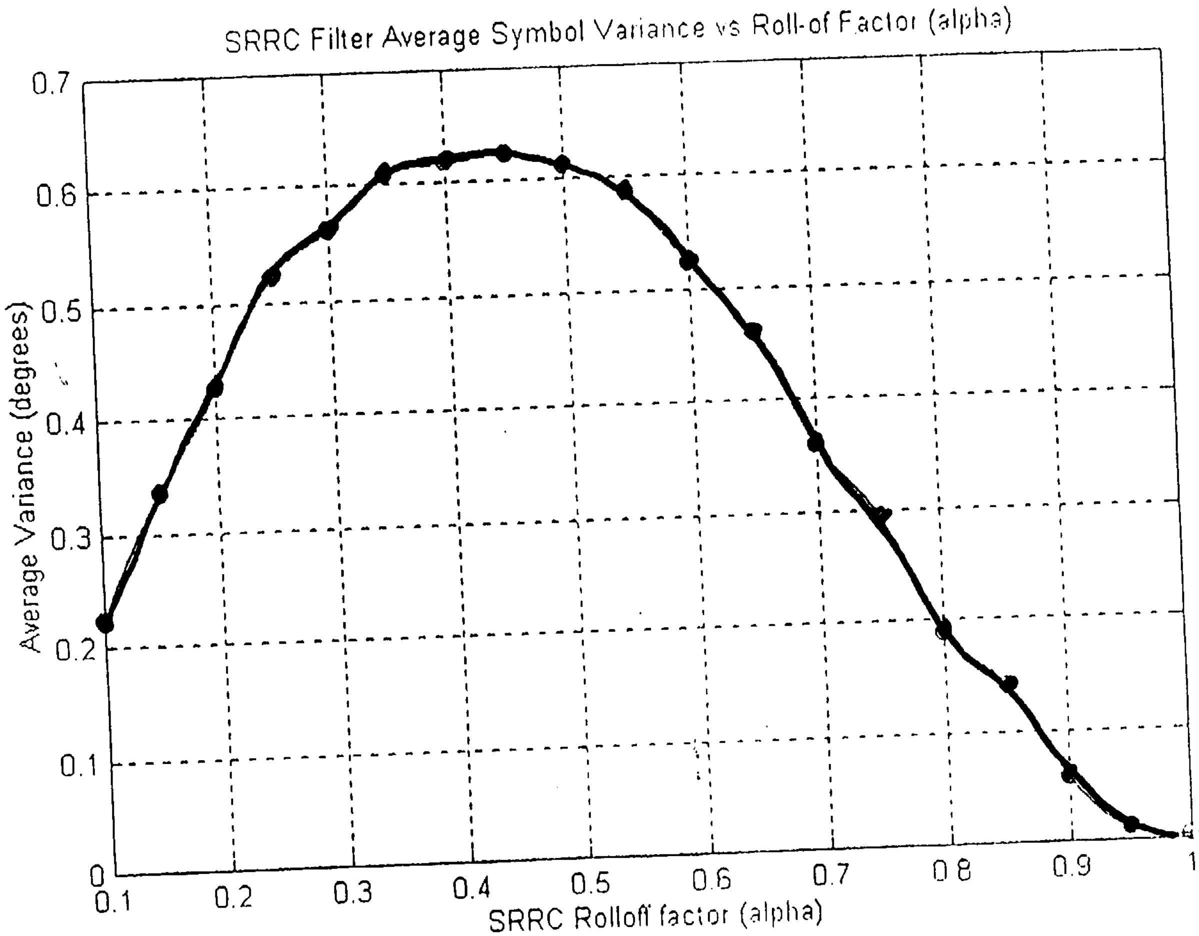
# RESULTS FOR 8PSK

## 8PSK Over Non-Linear Channel

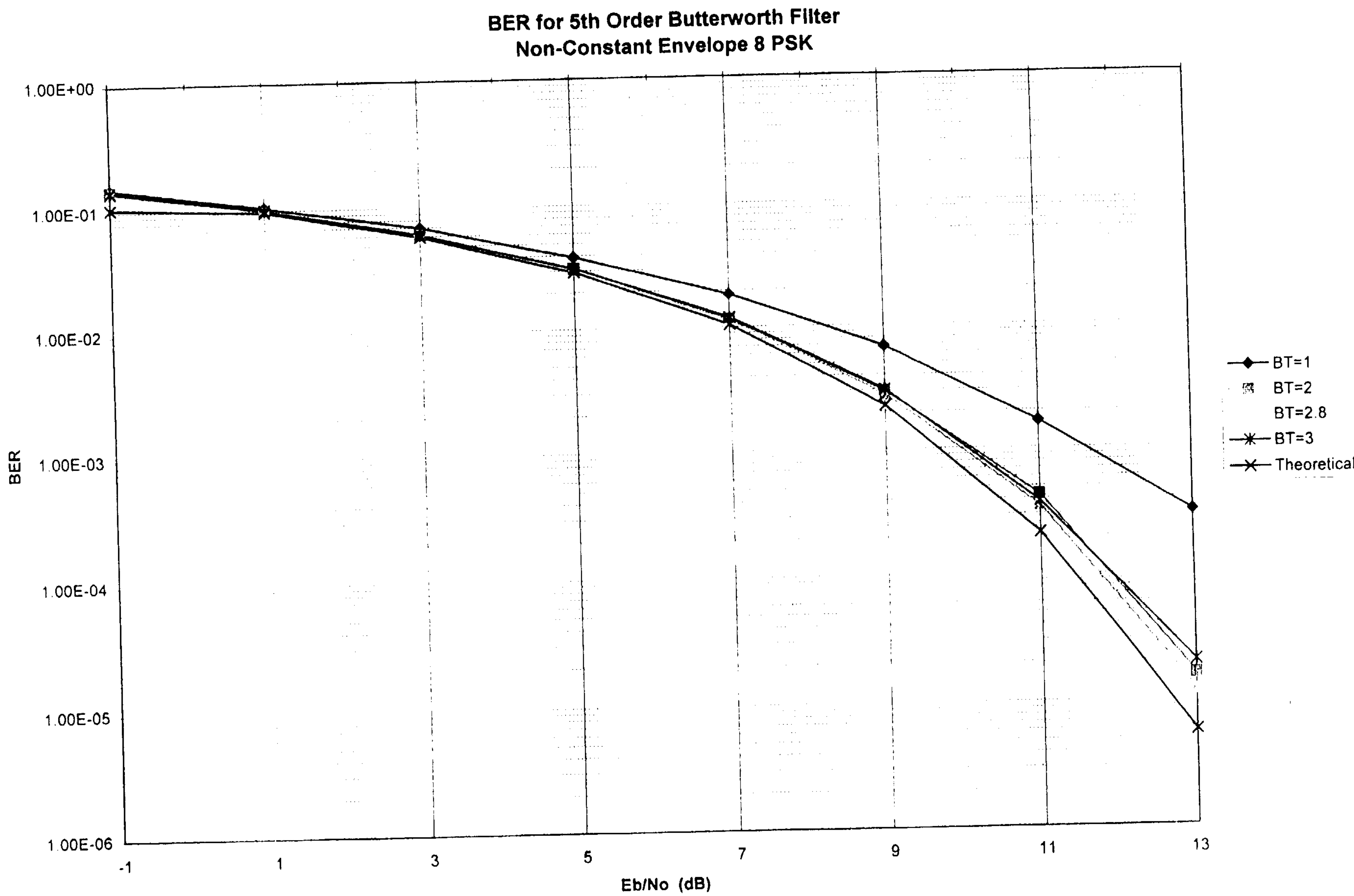



· Zoom of Average Symbol Variance vs BT for 3rd Order Bessel Filter

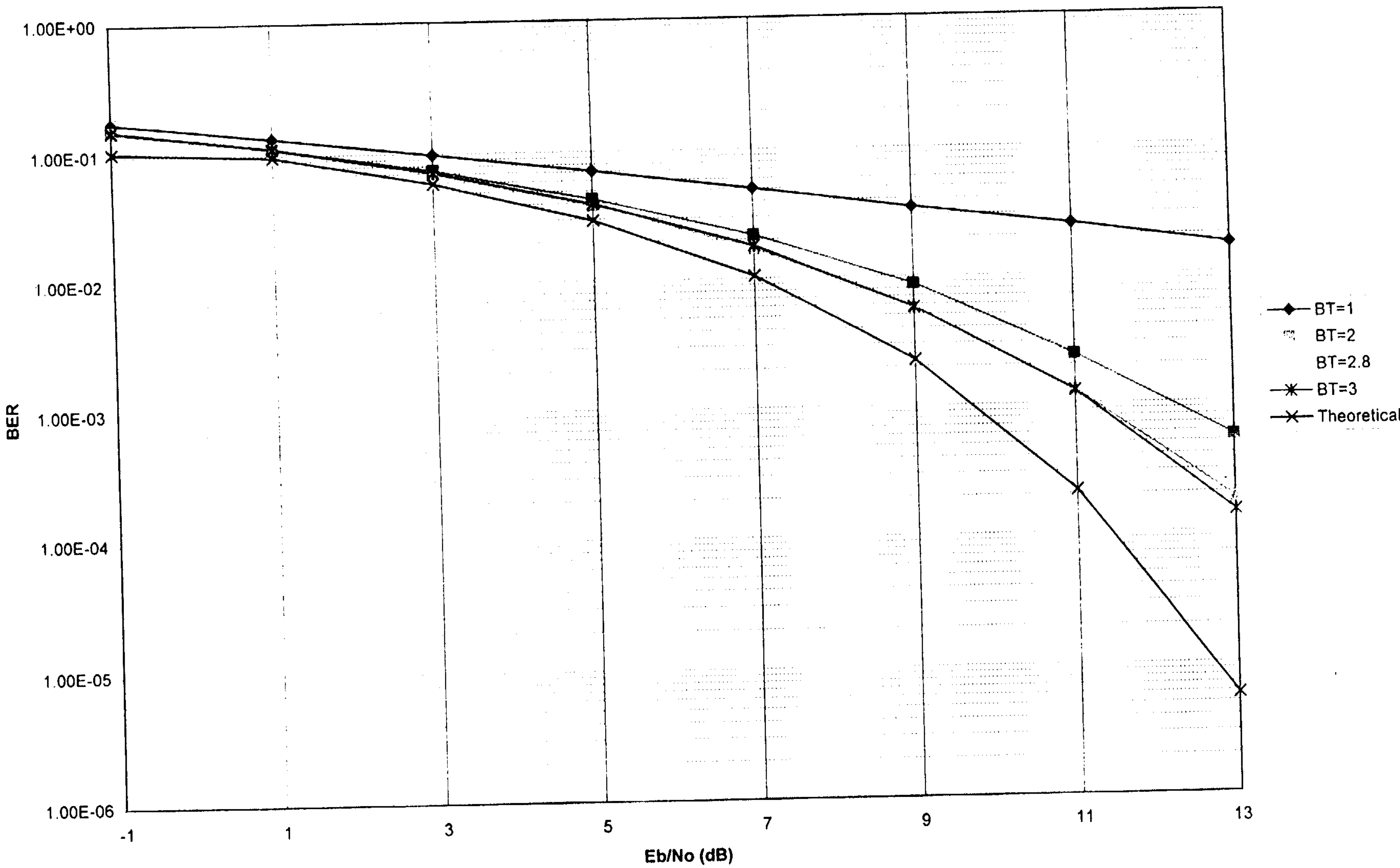
# RESULTS FOR 8PSK
## 8PSK Over Non-Linear Channel

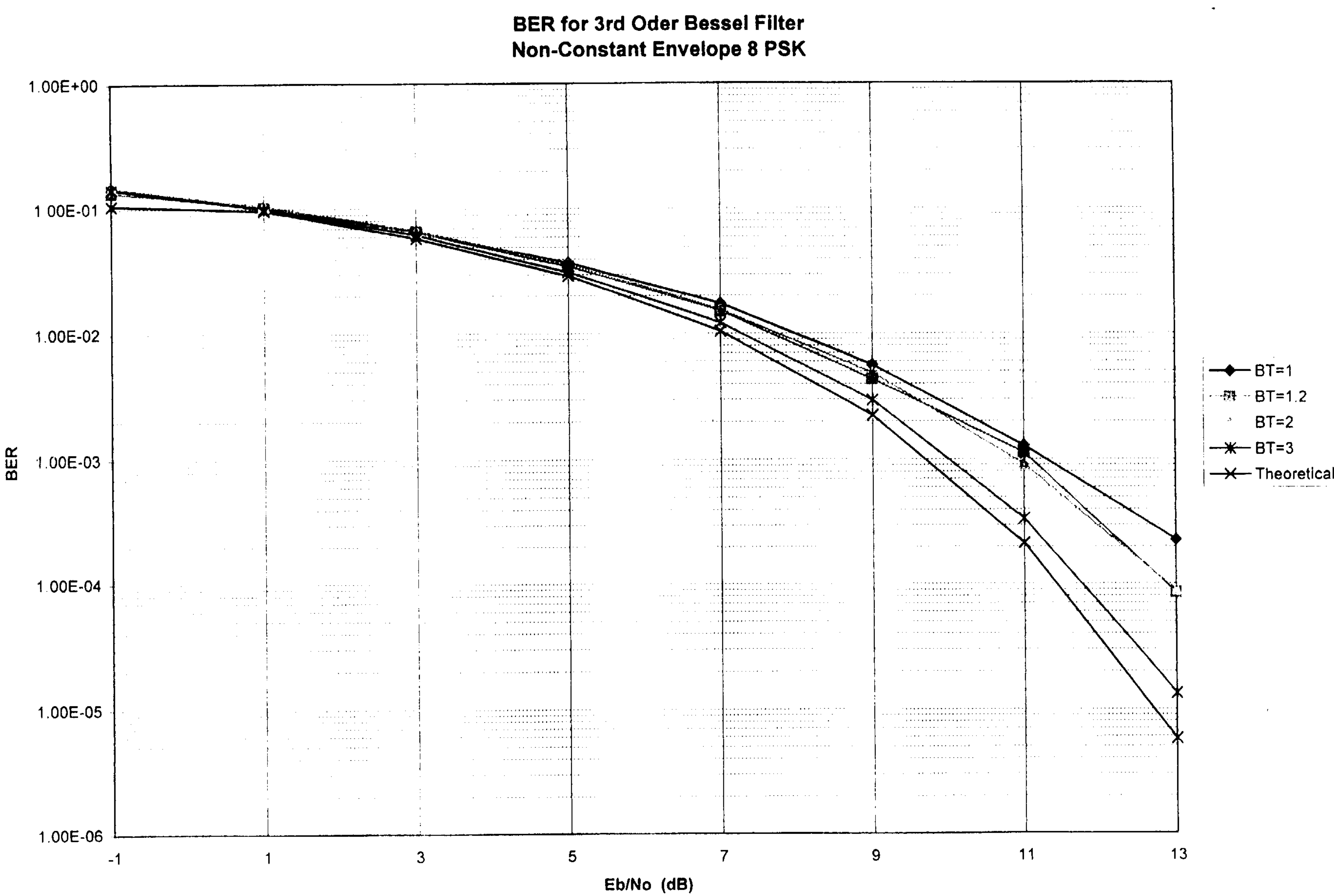


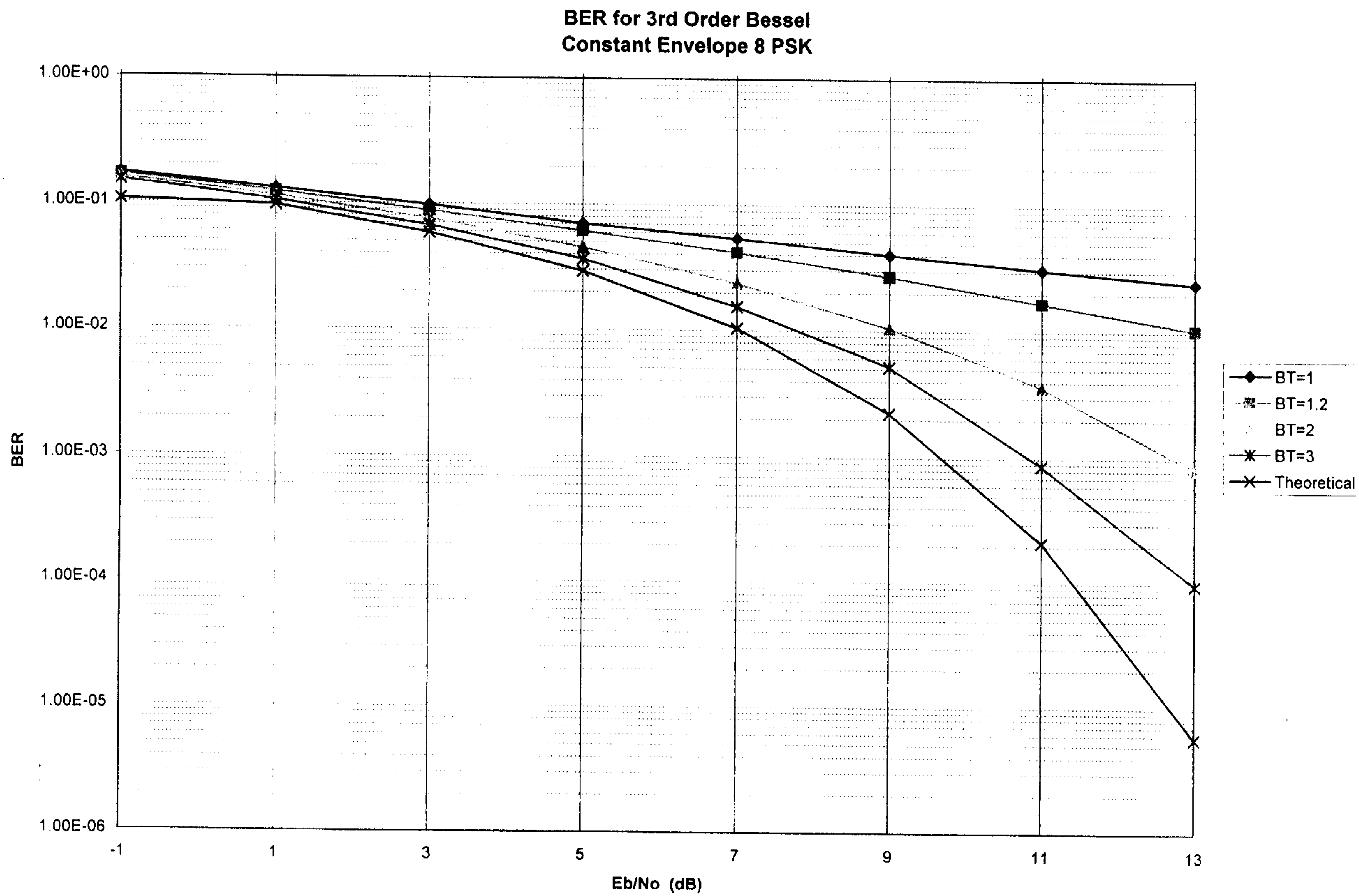

SRRC: Average Symbol Variance vs Roll-off factor ($\alpha$)

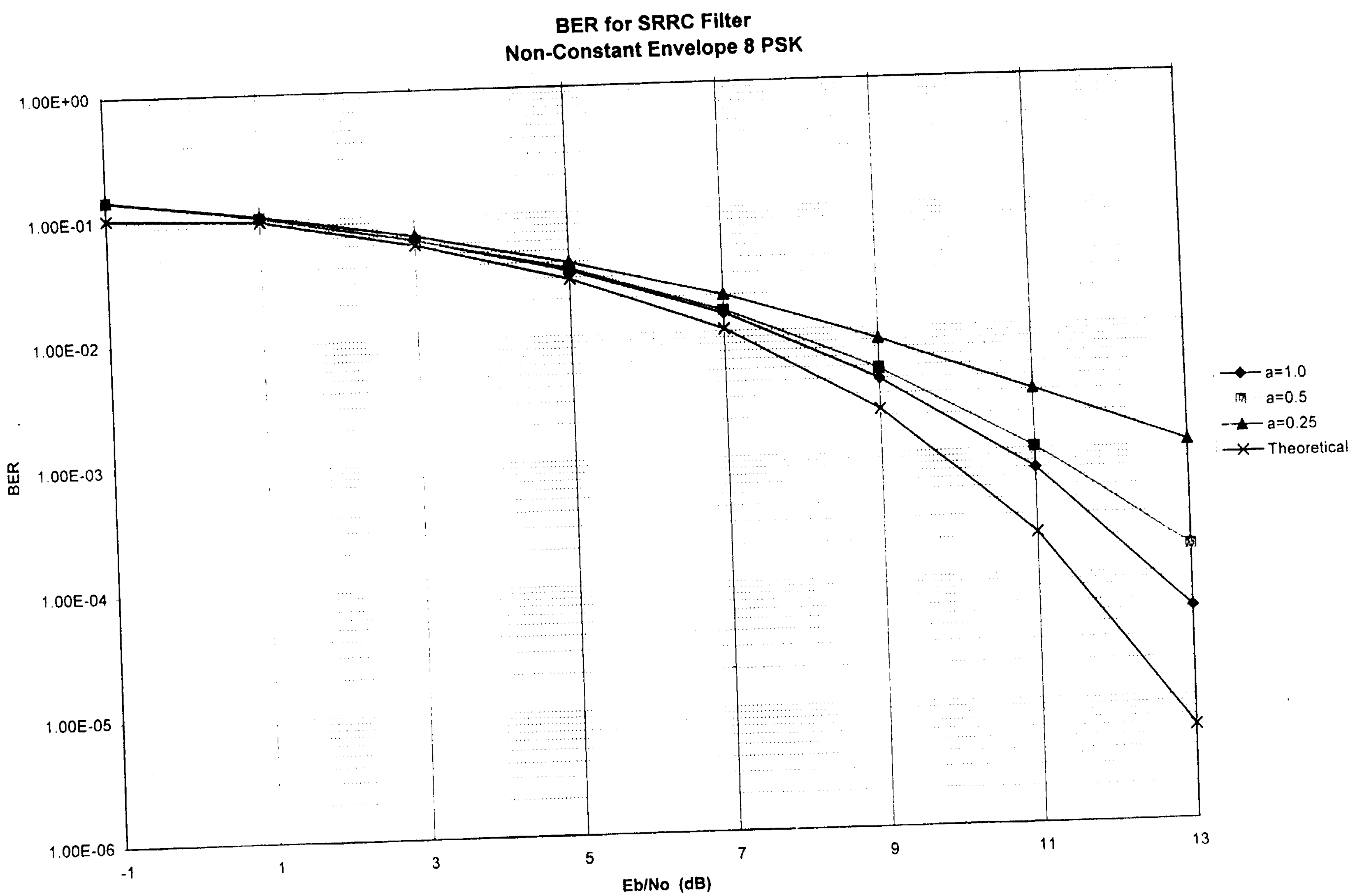

BER for 5th Order Butterworth Filter
Non-Constant Envelope 8 PSK
BER
1.00E+00
1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
-1
1
3
5
7
9
11
13
Eb/No (dB)
BT=1
BT=2
BT=2.8
BT=3
Theoretical

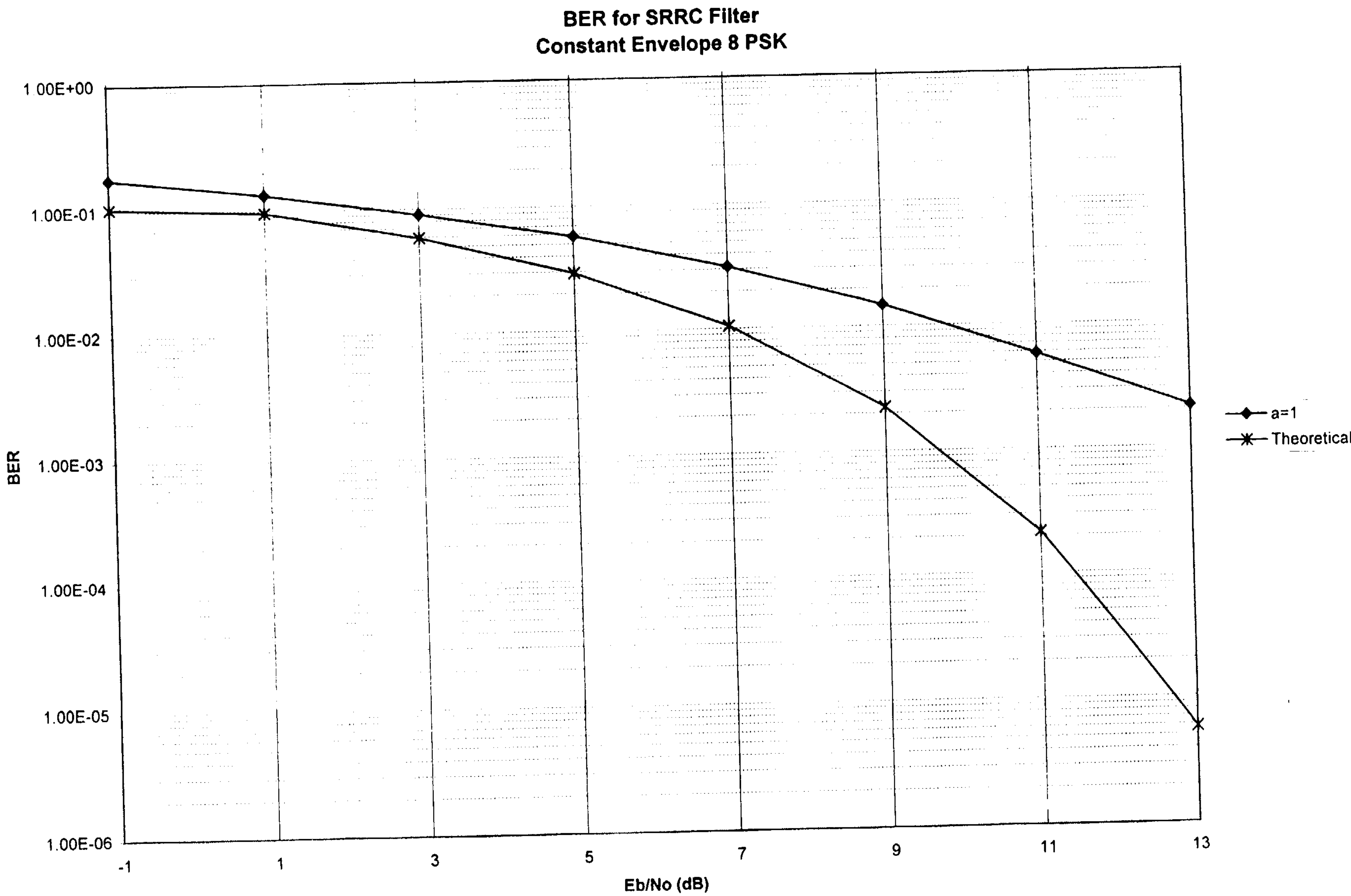
BER for 5th Order Butterworth Filter
Constant Envelope 8 PSK




BER for 3rd Oder Bessel Filter
Non-Constant Envelope 8 PSK
BER
1.00E+00
1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
-1
1
3
5
7
9
11
13
Eb/No (dB)
BT=1
BT=1.2
BT=2
BT=3
Theoretical


BER for 3rd Order Bessel
Constant Envelope 8 PSK
BER
1.00E+00
1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
-1
1
3
5
7
9
11
13
Eb/No (dB)
BT=1
BT=1.2
BT=2
BT=3
Theoretical


BER for SRRC Filter
Non-Constant Envelope 8 PSK
1.00E+00
1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
BER
-1
1
3
5
7
9
11
13
Eb/No (dB)
a=1.0
a=0.5
a=0.25
Theoretical

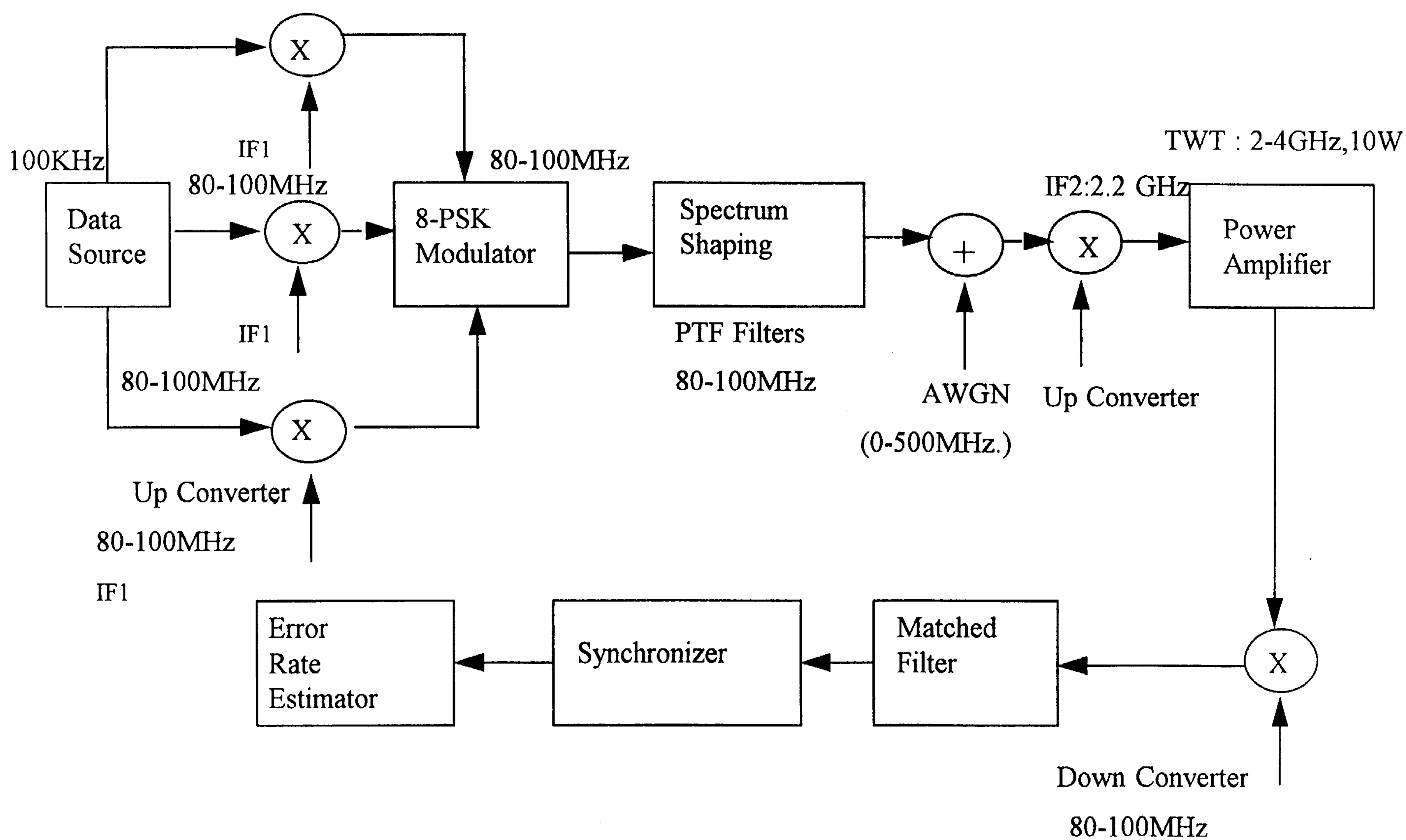

BER for SRRC Filter
Constant Envelope 8 PSK
1.00E+00
1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
BER
-1
1
3
5
7
9
11
13
Eb/No (dB)
a=1
Theoretical

# ISI Losses and Utilization Ratio

| Filter | Non-Const Envelope | | Constant Envelope | |
|---|---|---|---|---|
| Type | Utilization | ISI Loss | Utilization | ISI Loss |
| None | 1.00 | | 1.00 | |
| BW, BT=1 | 14.00 | 2.00 | 27.00 | |
| BW, BT=2 | 13.46 | 0.43 | 14.4 | |
| BW BT=2.8 | 10.00 | 0.29 | 10.8 | |
| BW BT=3 | 9.72 | 0.43 | 10.1 | |
| Bessel, bt=1 | 11.86 | 1.58 | 20 | |
| Bessel, bt=1.2 | 11.67 | 1.44 | 17.1 | |
| Bessel, bt=2 | 10.94 | 1.15 | 10.8 | |
| Bessel, bt=3 | 7.78 | 0.29 | 7.7 | |
| SRRC a=1 | 14.00 | 0.86 | 28.5 | |

# The Implementation of Pulse Shaping on 8-PSK Signaling Over a Non-Linear Satellite Channels

• **Block Diagram**



# (5) - CONCLUSIONS/FURTHER WORK

Conclusions:

- Improvement by a factor of 12 to 24 (BT=1) with filtering 8PSK; Constant Envelope 8PSK gives 24 to 48 improvement at BT=1.

- BER still not good enough

- For non-constant envelope: there is a pattern!

What is next:

- Obtain better models for High Power Amplifiers
- Simulations for higher order of BT;
- Implement in hardware;
- Find a close form equation for different filter orders.
- Use Equalization to improve BER
- Investigate spikes

# CODING TALK OUTLINE

1. INTRODUCTION TO TURBO CODES
2. ON TRANSPARENT TURBO CODES
3. TURBO CODES IN PULSED CW RFI
4. HIGH-RATE TURBO CODES
5. WSGT TURBO CODE TEST

# *INTRODUCTION TO TURBO CODES*

William E. Ryan, Asst. Prof., NMSU

March 11, 1997

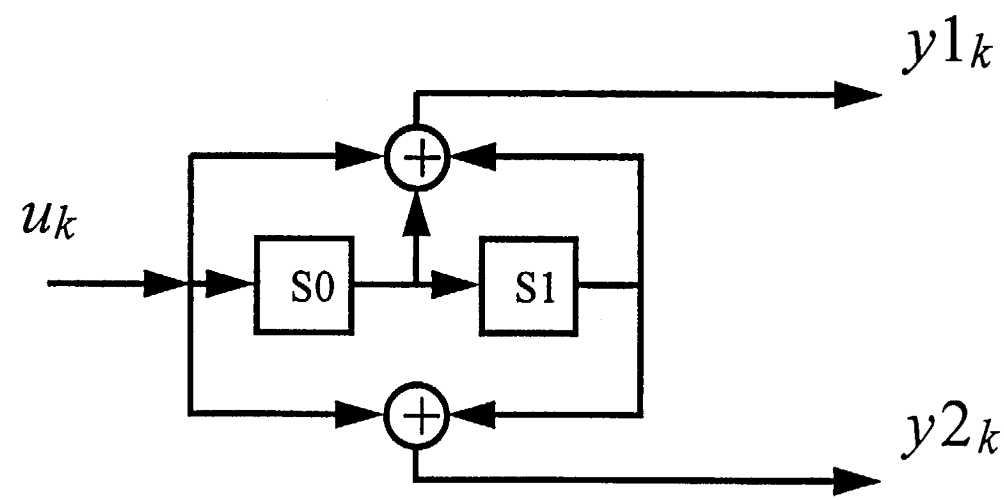
# NONRECURSIVE CONVOLUTIONAL CODES(CC)

**Example:** rate, r = 1/2.

G(D) = [g1(D) g2(D)]

$$g1 = 1\ 1\ 1 = 1 + D + D^2$$

$$g2 = 1\ 0\ 1 = 1 + D^2$$



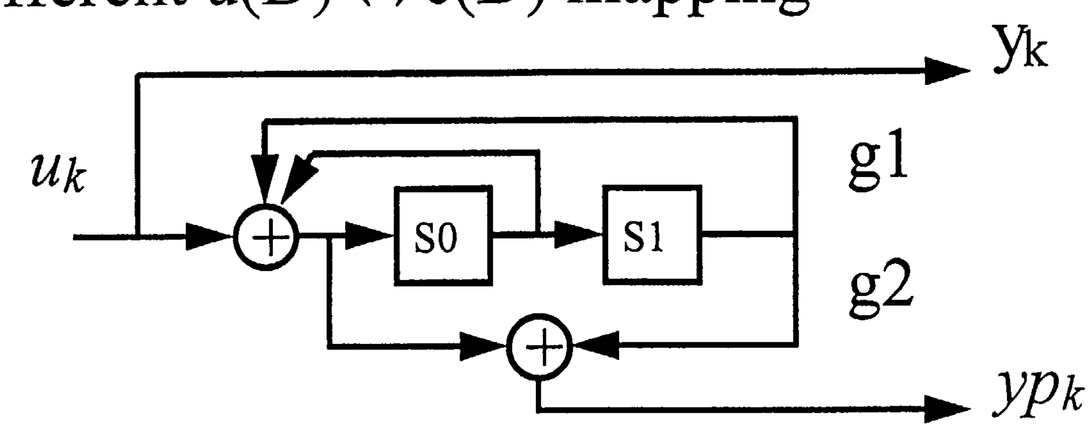
# *RECURSIVE SYSTEMATIC CC (RSCC)*

Remember G(D) = [g1(D)   g2(D)] from non-recursive CC

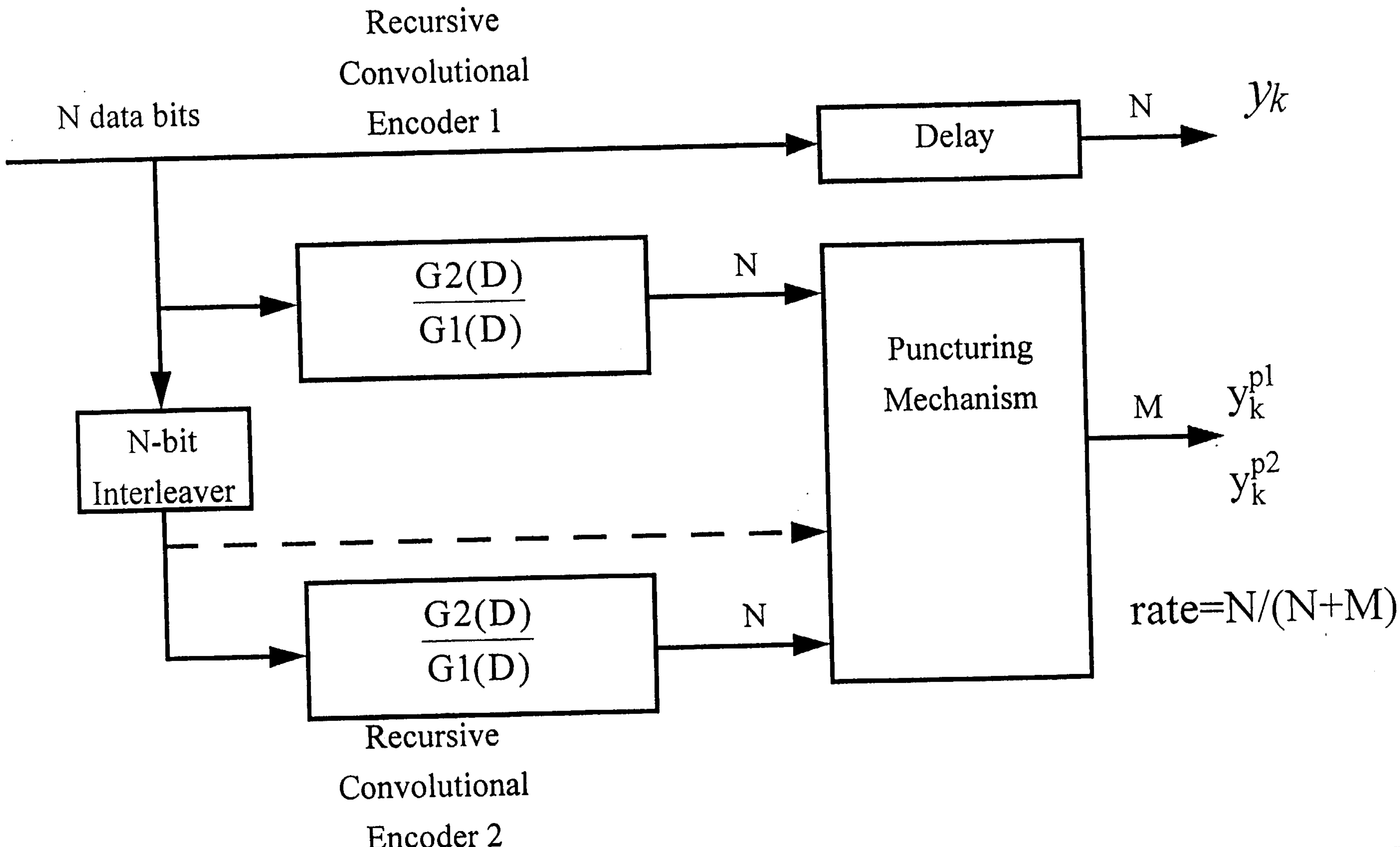
**Example:** $G(D) = \left[\; 1 \quad \frac{g2(D)}{g1(D)} \right]$ for recursive CC

* same set of code sequences c(D) = u(D) G(D)

* different u(D) ↔ c(D) mapping

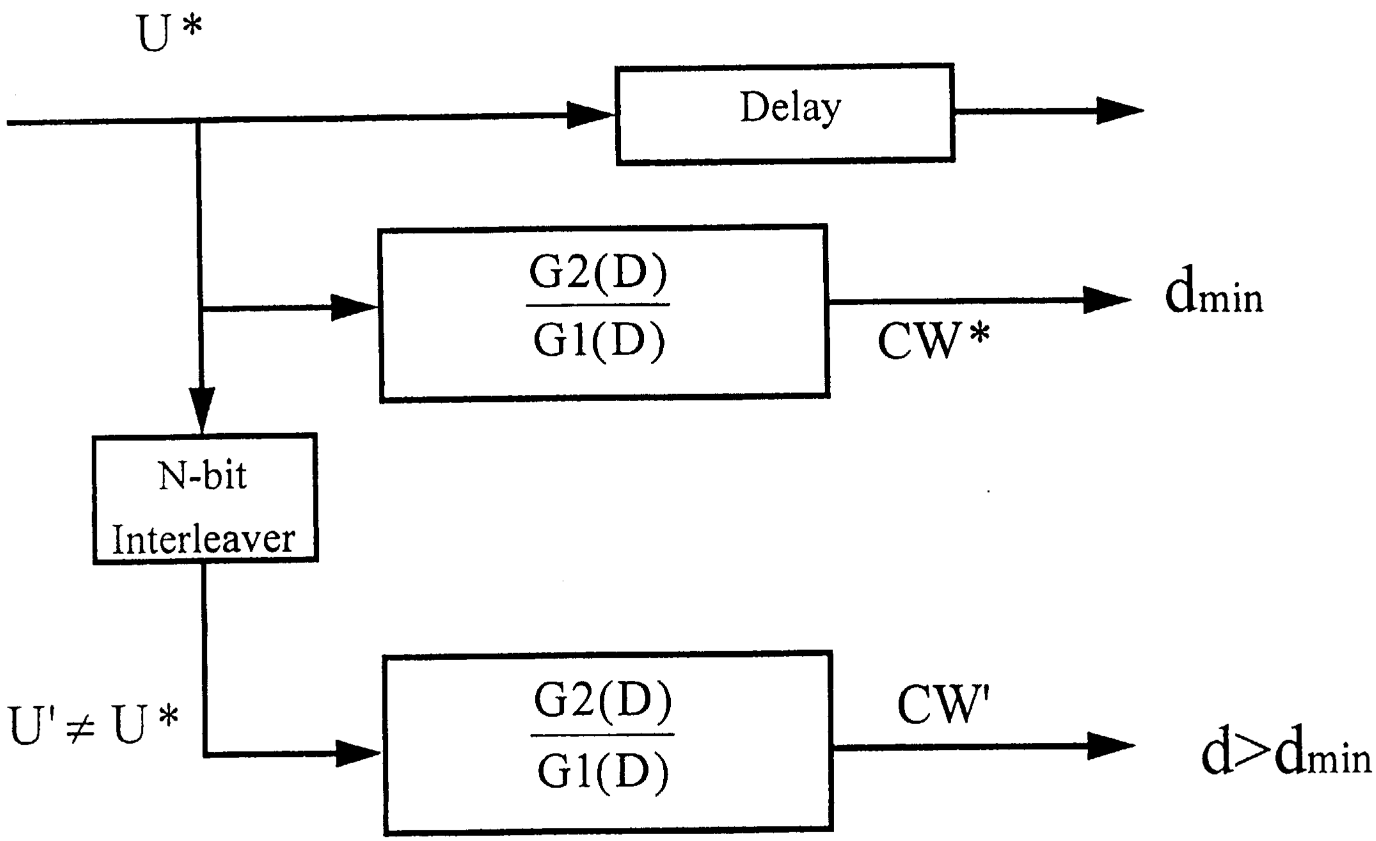


# TC ENCODER

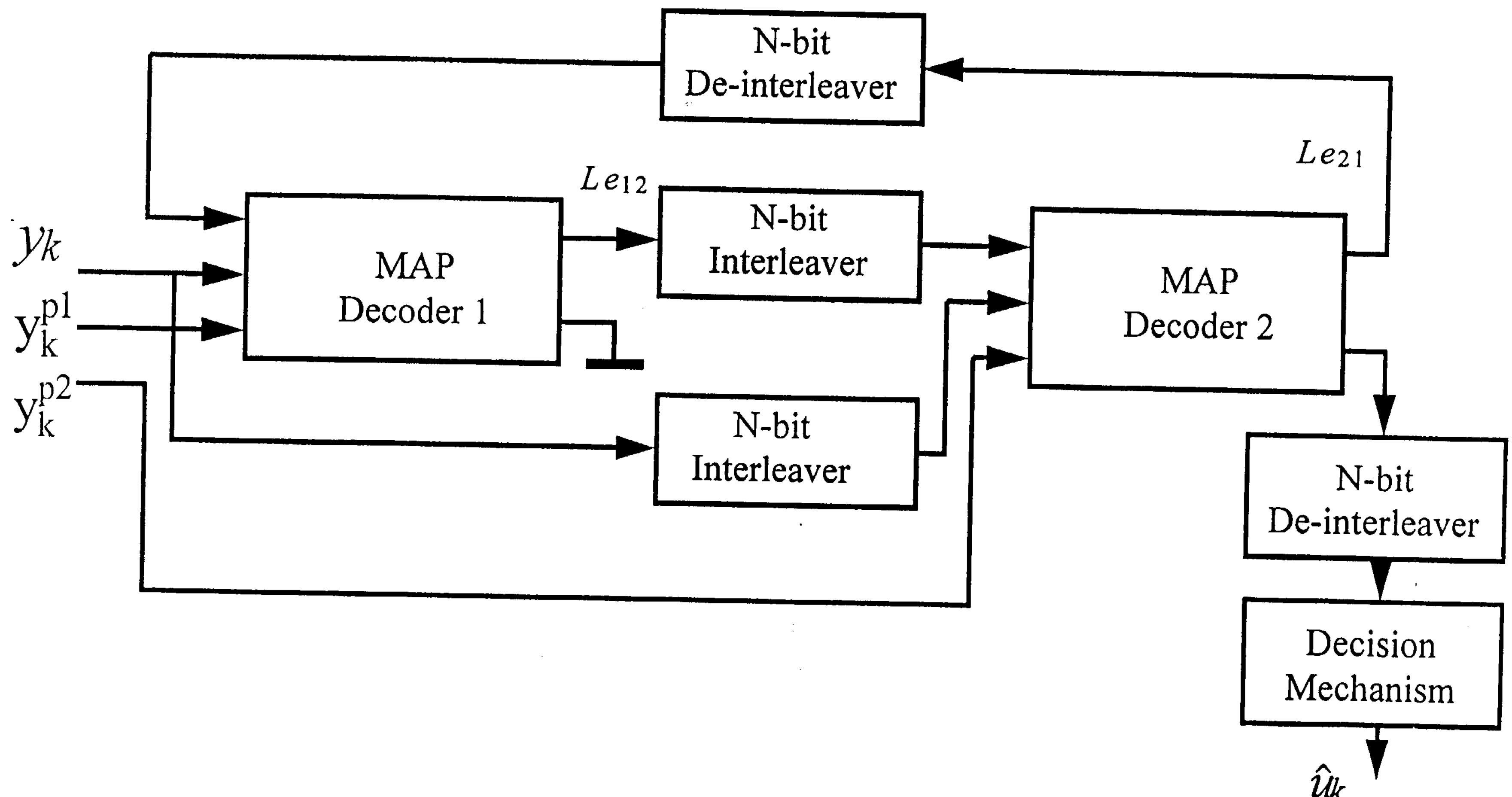


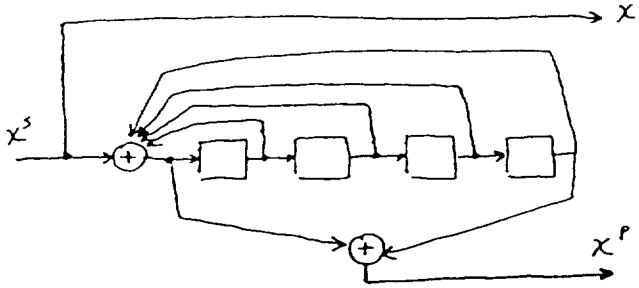
Recursive
Convolutional
Encoder 1
N data bits
Delay
N
$y_k$
$\frac{G2(D)}{G1(D)}$
N
Puncturing
Mechanism
M
$y_k^{p1}$
$y_k^{p2}$
N-bit
Interleaver
$\frac{G2(D)}{G1(D)}$
N
rate=N/(N+M)
Recursive
Convolutional
Encoder 2

# TC ENCODER



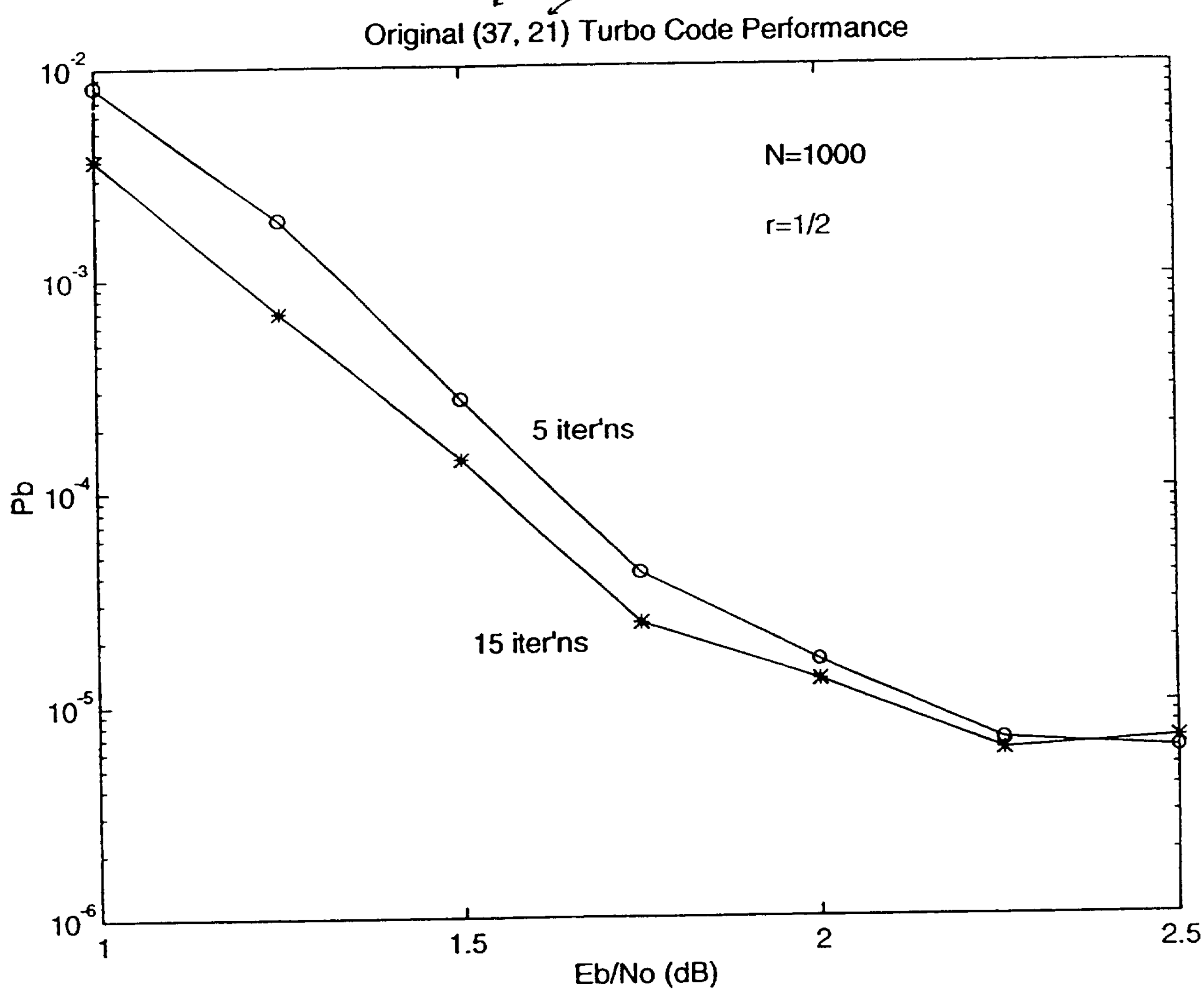
# ITERATIVE DECODER FOR TC



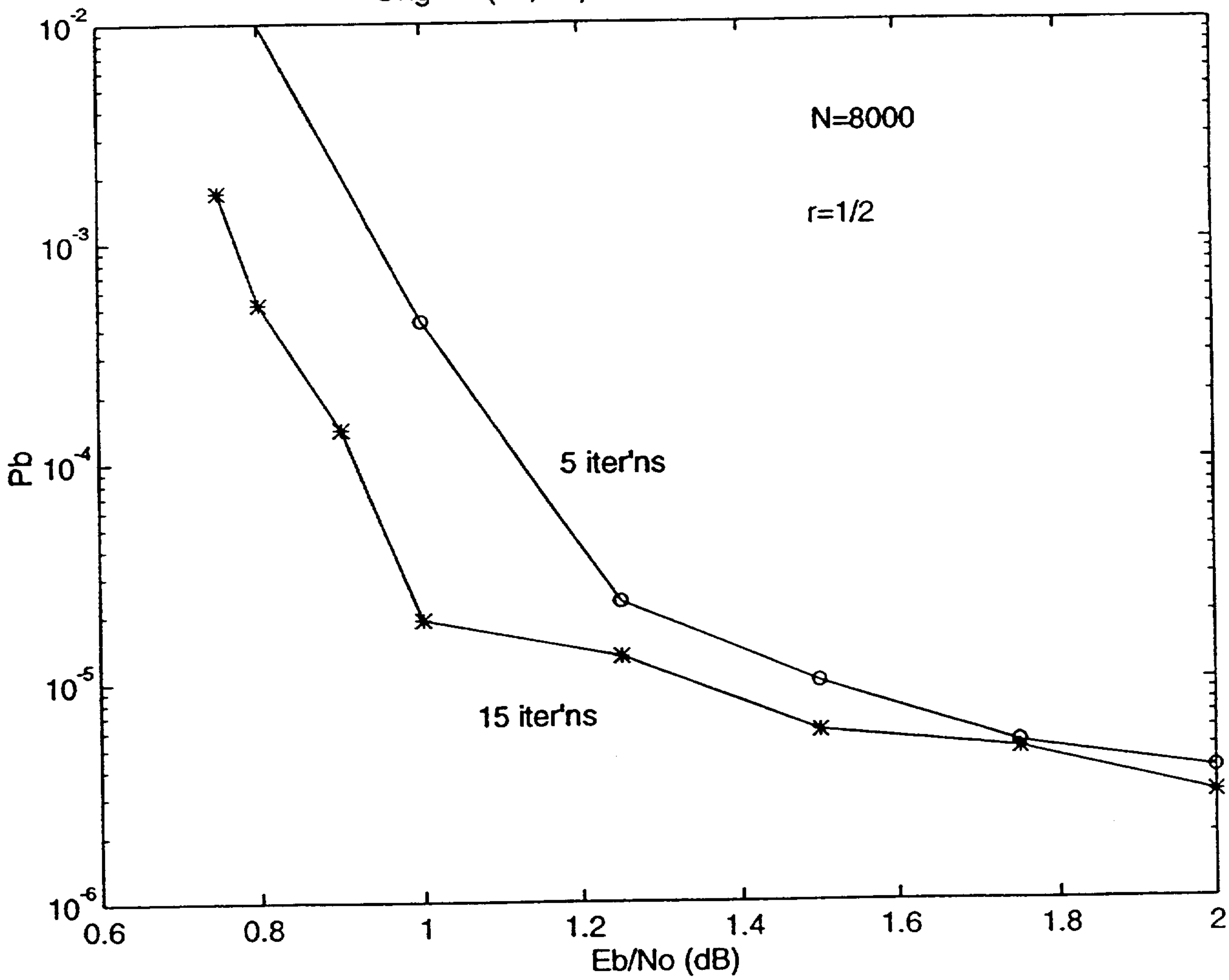



$\bar{d} = 37_{oct} = 11111 = 1 + D + D^2 + D^3 + D^4 = d(D)$

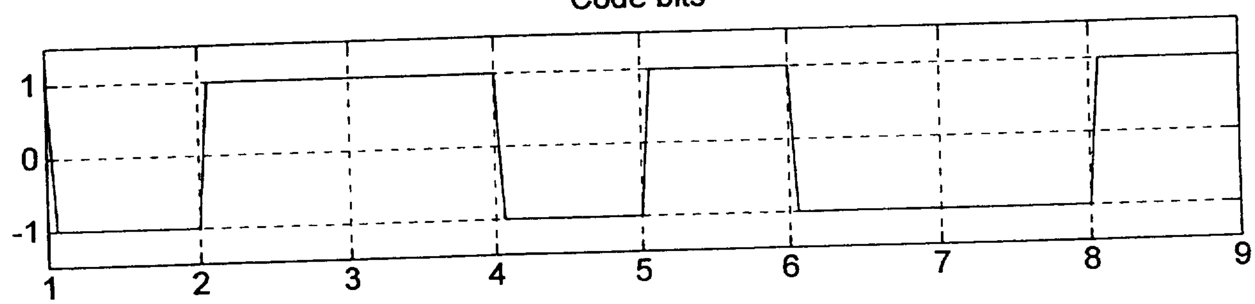
$\bar{n} = 21_{oct} = 10001 = 1 + D^4 = n(D)$



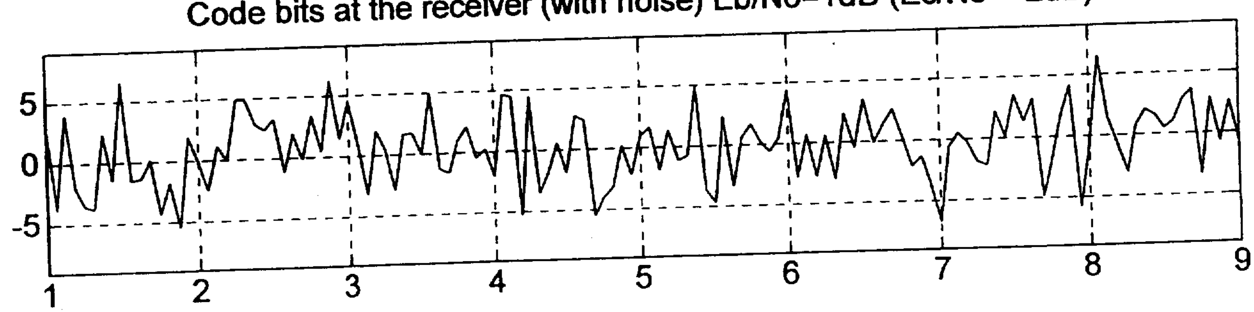
Original (37, 21) Turbo Code Performance



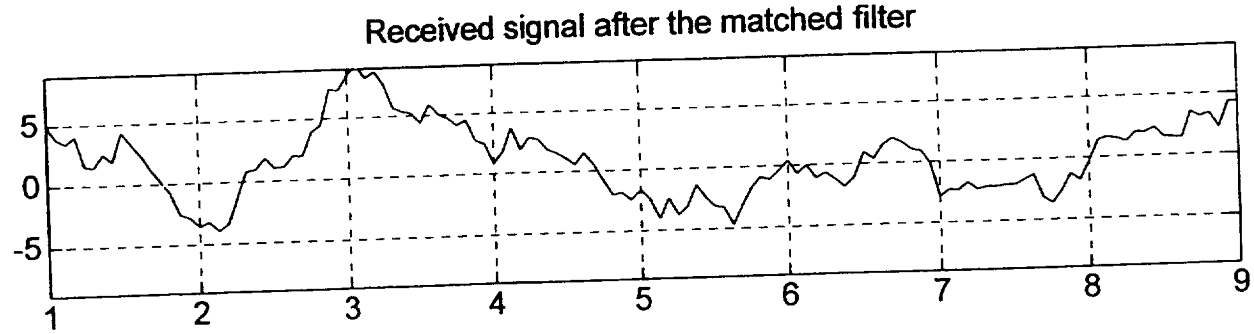
Code bits




Code bits at the receiver (with noise) Eb/No=1dB (Ec/No= -2dB)




Received signal after the matched filter

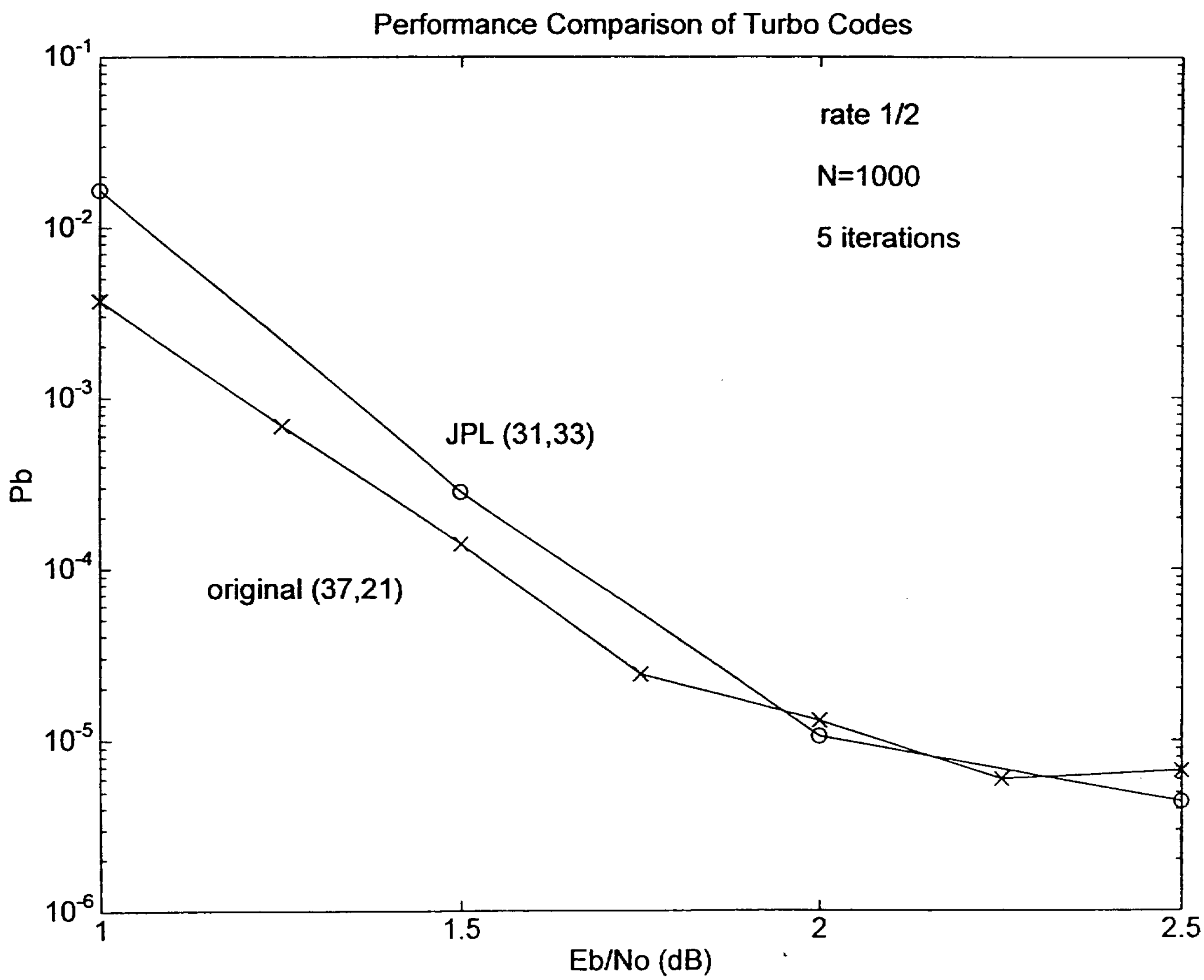


# On the Transparency of Turbo Codes

William E. Ryan, Assistant Professor
Omer Acikel, Ph.D. student

New Mexico State University

March 1997


Performance Comparison of Turbo Codes
rate 1/2
N=1000
5 iterations
JPL (31,33)
original (37,21)
Pb
Eb/No (dB)
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
1
1.5
2
2.5

# OUTLINE

I. Introduction to Transparent Codes

II. Application to Turbo Codes

III. Simulation Results

# I. Introduction to Transparent Codes

**Notation**

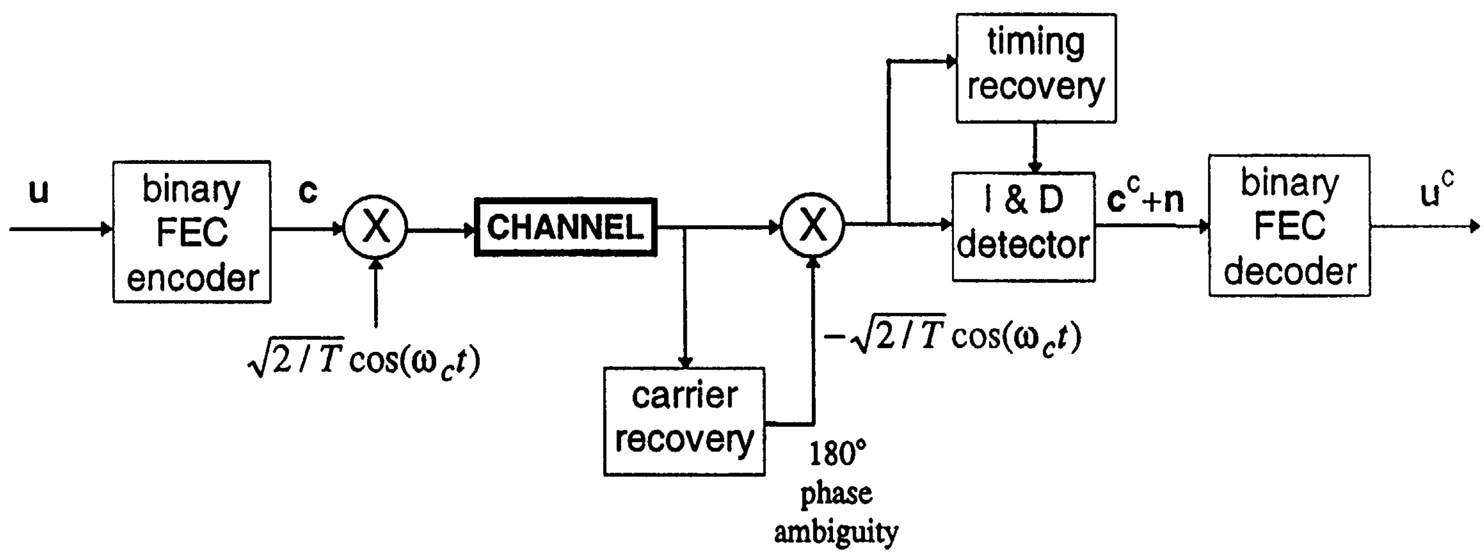
1. By $\mathbf{u} \leftrightarrow \mathbf{c}$ we mean the message word $\mathbf{u}$ is mapped to the codeword $\mathbf{c}$ by the encoder.
2. $\mathbf{u}^c$ and $\mathbf{c}^c$ are the logical complements of $\mathbf{u}$ and $\mathbf{c}$ (binary codes are assumed).

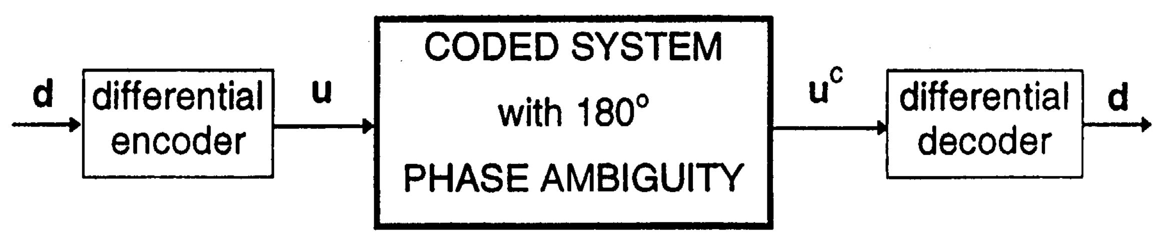
**Definition**

A code is *transparent* if $\mathbf{u} \leftrightarrow \mathbf{c}$ implies $\mathbf{u}^c \leftrightarrow \mathbf{c}^c$.

- The utility of transparent codes -- also called rotationally invariant codes -- arises as a result of the ambiguous lock phenomenon of carrier recovery circuits.

## Illustration

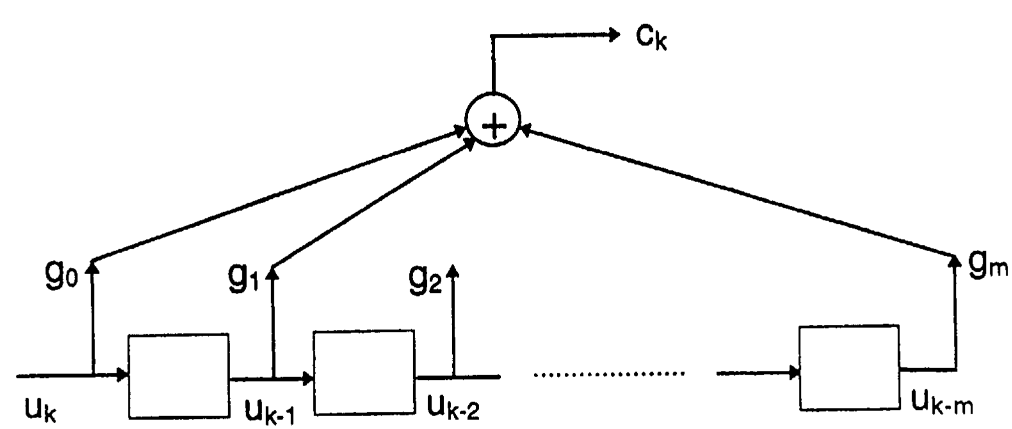


# II. Application to Turbo Codes

(These results are due to Prof. Steve Wilson of the University of Virginia)

## Review of Transparent *Non-Recursive* Convolutional Codes




Result: A rate $1/n$ non-recursive convolutional code is transparent if and only if the number of taps in each of its $n$ generators is odd, i.e., $w_H[g_i(D)]$ are all odd.

PROOF: When **u** is input, the encoder output is

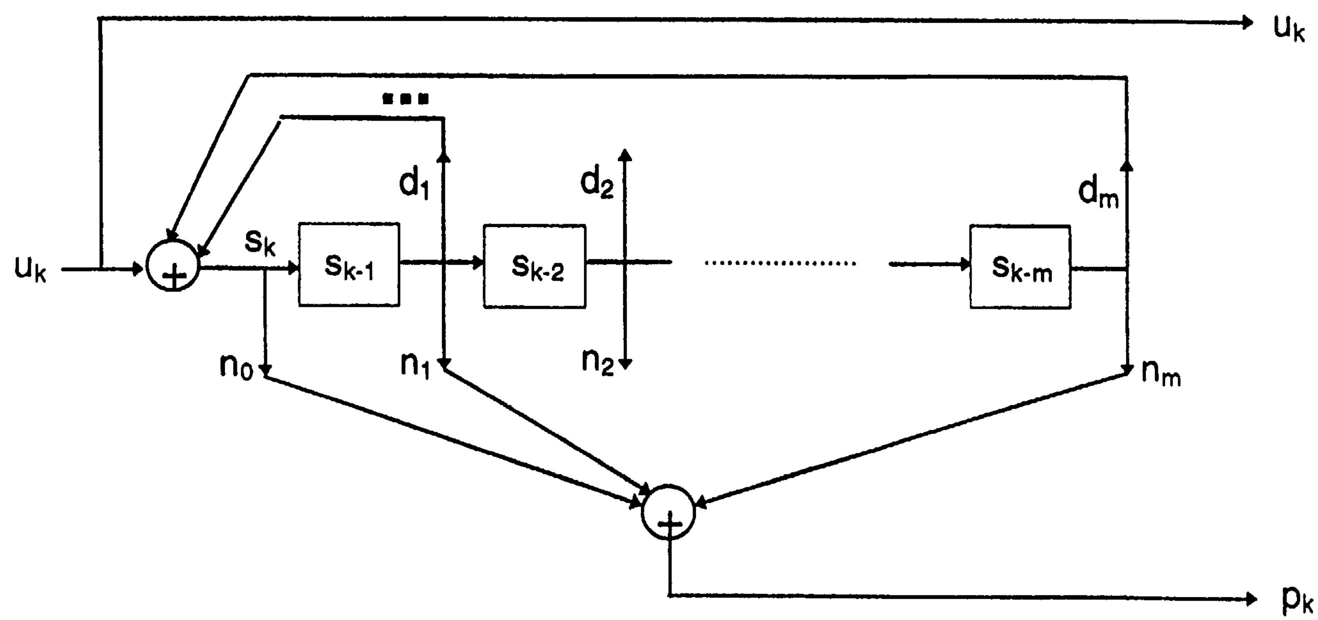
$$c_k = \sum_{j=0}^{m} u_{k-j} g_j \,.$$

When $\mathbf{u}^c$ is input, the encoder output is

$$\begin{aligned} c'_k &= \sum_{j=0}^{m} u^c_{k-j} g_j \\ &= \sum_{j=0}^{m} \left(u_{k-j} + 1\right) g_j \\ &= \sum_{j=0}^{m} u_{k-j} g_j + \sum_{j=0}^{m} g_j \\ &= c_k + 1 \qquad \text{iff the number of nonzero } g_j \text{ is odd} \\ &= c^c_k \qquad \text{iff the number of nonzero } g_j \text{ is odd} \end{aligned}$$

■

## The Result for *Recursive* Convolutional Codes




RESULT: A recursive convolutional code cannot be transparent, but can be "quasi-transparent" in the sense that $(\mathbf{u}, \sigma_0) \leftrightarrow \mathbf{c}$ implies $(\mathbf{u}^c, \sigma_0{}^c) \leftrightarrow \mathbf{c}^c$ ($\sigma_0$ is the initial state of the encoder). The code will be quasi-transparent whenever both $w_H[n(D)]$ and $w_H[d(D)]$ are odd.

PROOF: We note that when $\mathbf{u}^c$ is input:

1. the systematic part of the codeword $\mathbf{c} = [\ \mathbf{u} \mid \mathbf{p}\ ]$ is automatically complemented.
2. the parity is complemented if and only if $(s_k, s_{k-1}, \ldots, s_{k-m})$ is complemented and $w_H[n(D)]$ is odd (from nonrecursive result).

- Thus, when $w_H[n(D)]$ is odd, $p_k$ is complemented if $s_k$ and the state $\sigma_k = (s_{k-1}, s_{k-2}, \ldots, s_{k-m})$ are complemented, for all $k \geq 0$.
- But, $s_k$ and $\sigma_k = (s_{k-1}, s_{k-2}, \ldots, s_{k-m})$ will be complemented, for all $k \geq 0$, if:
  1. the encoder initialized to $\sigma_0^c$
  2. $w_H[d(D)]$ is odd

*Proof of previous bullet*: When $\mathbf{u}$ is input,

$$s_k = u_k + \sum_{j=1}^{m} s_{k-j} d_j \ .$$

When $\mathbf{u}^c$ is input and the encoder is initialized to $\sigma_0{}^c = (s_{-1}{}^c, s_{-2}{}^c, \ldots, s_{-m}{}^c)$,

$$s_0' = u_0^c + \sum_{j=1}^{m} s_{-j}^c d_j$$

$$= u_0 + 1 + \sum_{j=1}^{m} \left(s_{-j} + 1\right) d_j$$

$$= u_0 + \sum_{j=1}^{m} s_{-j}\, d_j + 1 + \sum_{j=1}^{m} d_j$$

$$= u_0 + \sum_{j=1}^{m} s_{-j}\, d_j + \sum_{j=0}^{m} d_j$$

$$= s_0 + 1 \quad \text{iff } w_H[d(D)] \text{ is odd}$$

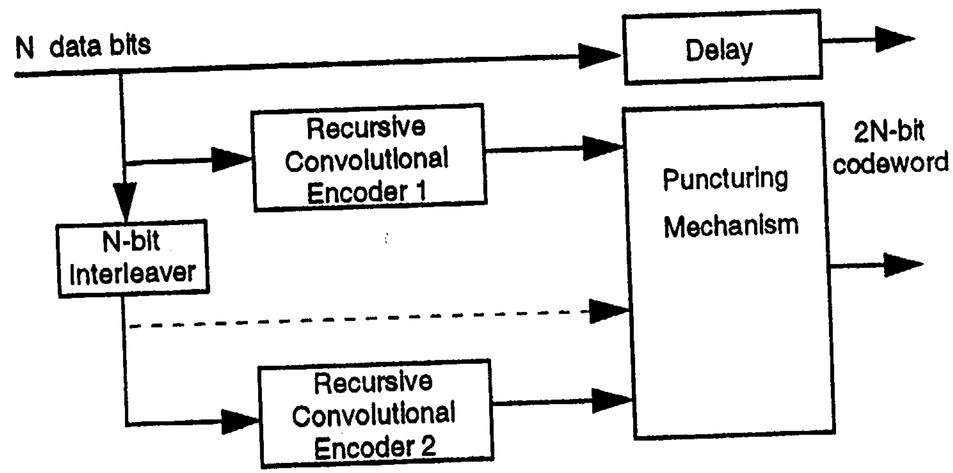
$$= s_0^c \quad \text{iff } w_H[d(D)] \text{ is odd}$$

Thus, $s_0, s_{-1}, \ldots, s_{-m}$ will each be complemented so that $\sigma_1 = (s_0, s_{-1}, \ldots, s_{-m+1})$ will be complemented (relative to when **u** is input).

Following, identical steps, can show (inductively) that $s_k$ and $\boldsymbol{\sigma}_k = (s_{k-1}, s_{k-2}, \ldots, s_{k-m})$ will be complemented, for all $k \geq 0$, provided the encoder initialized to $\sigma_0^c$ and $w_H[d(D)]$ is odd.

■

## Implications for Turbo Codes




Because turbo codes employ two (or more) recursive convolutional codes, a turbo code is also quasi-transparent.

Thus, on channels with ambiguities, the decoder may see the situation $(\mathbf{u}, \sigma_0) \leftrightarrow \mathbf{c}$ (when properly locked) or the situation $(\mathbf{u}^c, \sigma_0{}^c) \leftrightarrow \mathbf{c}^c$ (when locked 180° out of phase).

As a result, the constituent decoders must initialize their state probabilities to account for the 50% chance of locking out of phase and the encoder appearing to start in the all-ones state:

$$
\begin{aligned}
\text{D1: } \alpha_0^{(1)}(s) &= 0.5, \quad \text{for } s = 0 \text{ and } 2^m - 1 \\
&= 0, \quad \text{else} \\
\beta_N^{(1)}(s) &= 0.5, \quad \text{for } s = 0 \text{ and } 2^m - 1 \\
&= 0, \quad \text{else}
\end{aligned}
$$

$$
\begin{aligned}
\text{D2: } \alpha_0^{(2)}(s) &= 0.5, \quad \text{for } s = 0 \text{ and } 2^m - 1 \\
&= 0, \quad \text{else} \\
\beta_N^{(2)}(s) &= \alpha_N^{(2)}(s), \quad \text{for all } s
\end{aligned}
$$

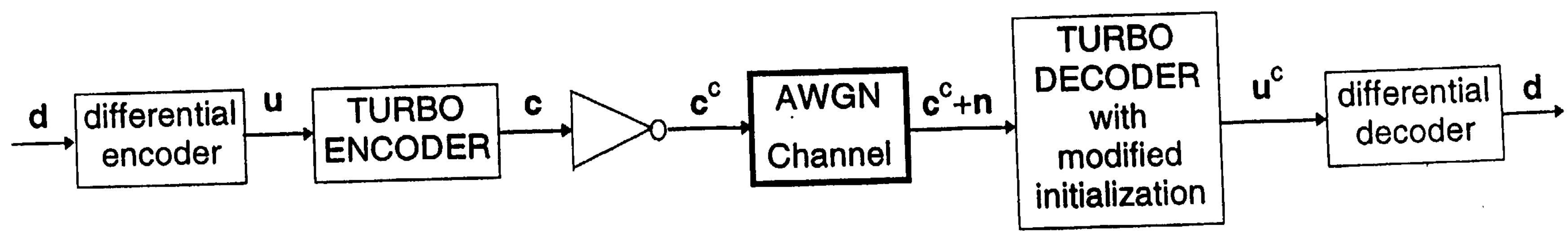
We can expect some degradation relative to the ideal due to decoder's uncertainty in the encoder's initial state.

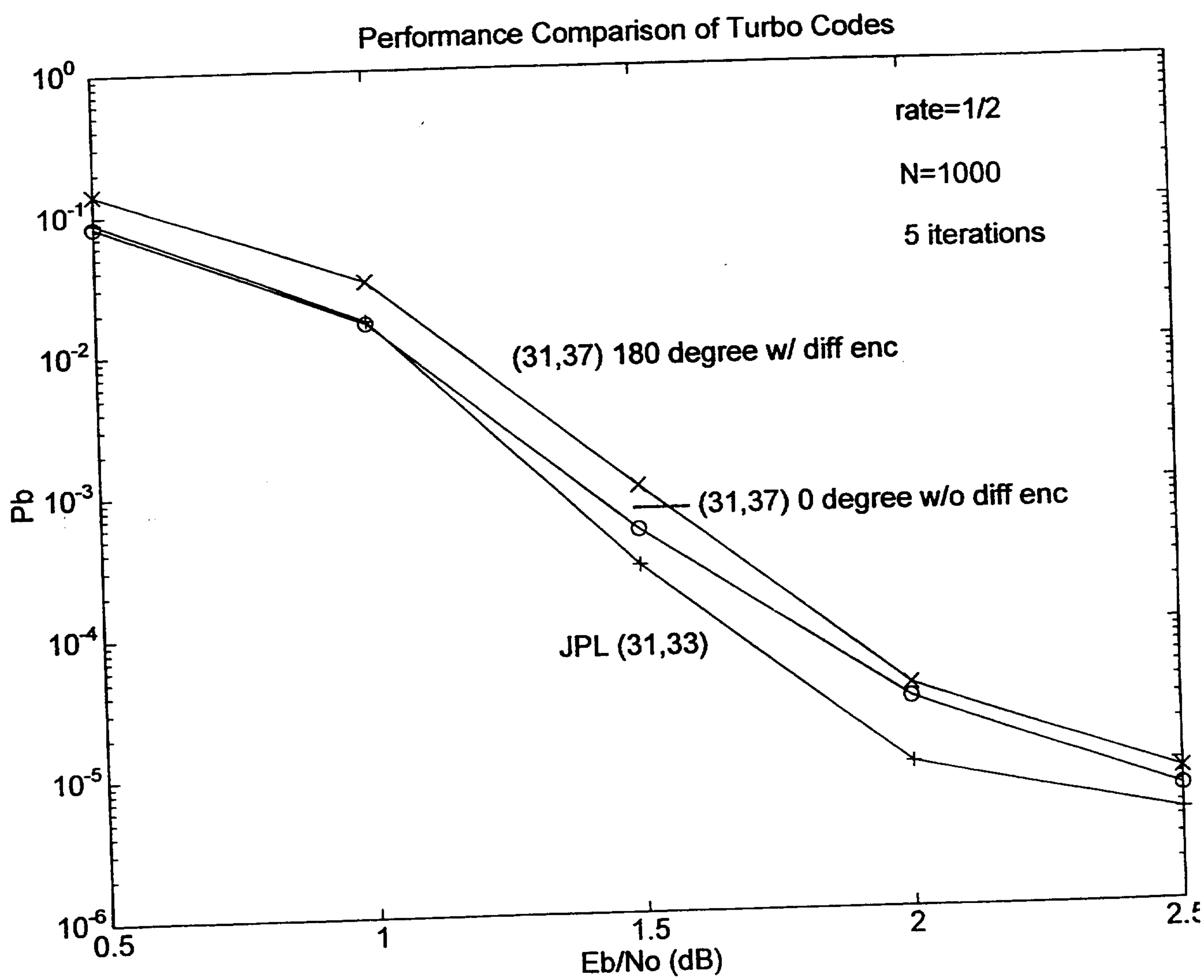
## III. Simulation Results

A turbo code with $w_H[n(D)]$ and $w_H[d(D)]$ odd was selected from "Design of parallel concatenated codes," by S. Benedetto and G. Montorsi, *IEEE Trans. Comm.*, May 1996:

$$d(D) = 31_{\text{octal}} \qquad n(D) = 37_{\text{octal}} \qquad \text{(16 states)}$$

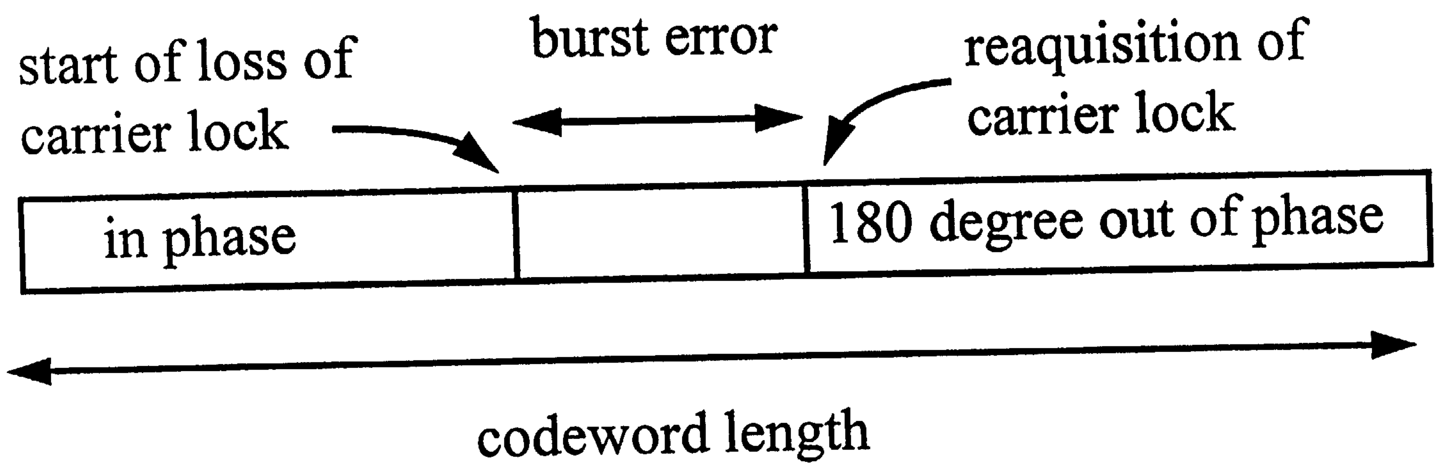
*Simulation Model*



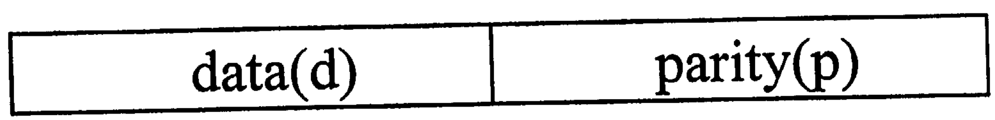


Performance Comparison of Turbo Codes
rate=1/2
N=1000
5 iterations
(31,37) 180 degree w/ diff enc
(31,37) 0 degree w/o diff enc
JPL (31,33)
Pb
$10^0$
$10^{-1}$
$10^{-2}$
$10^{-3}$
$10^{-4}$
$10^{-5}$
$10^{-6}$
0.5
1
1.5
2
Eb/No (dB)

# *BURST ERROR RESULTS with The (31,37) TRANSPARENT CODE*




**pattern1:**




**pattern2:** dpdpdp......

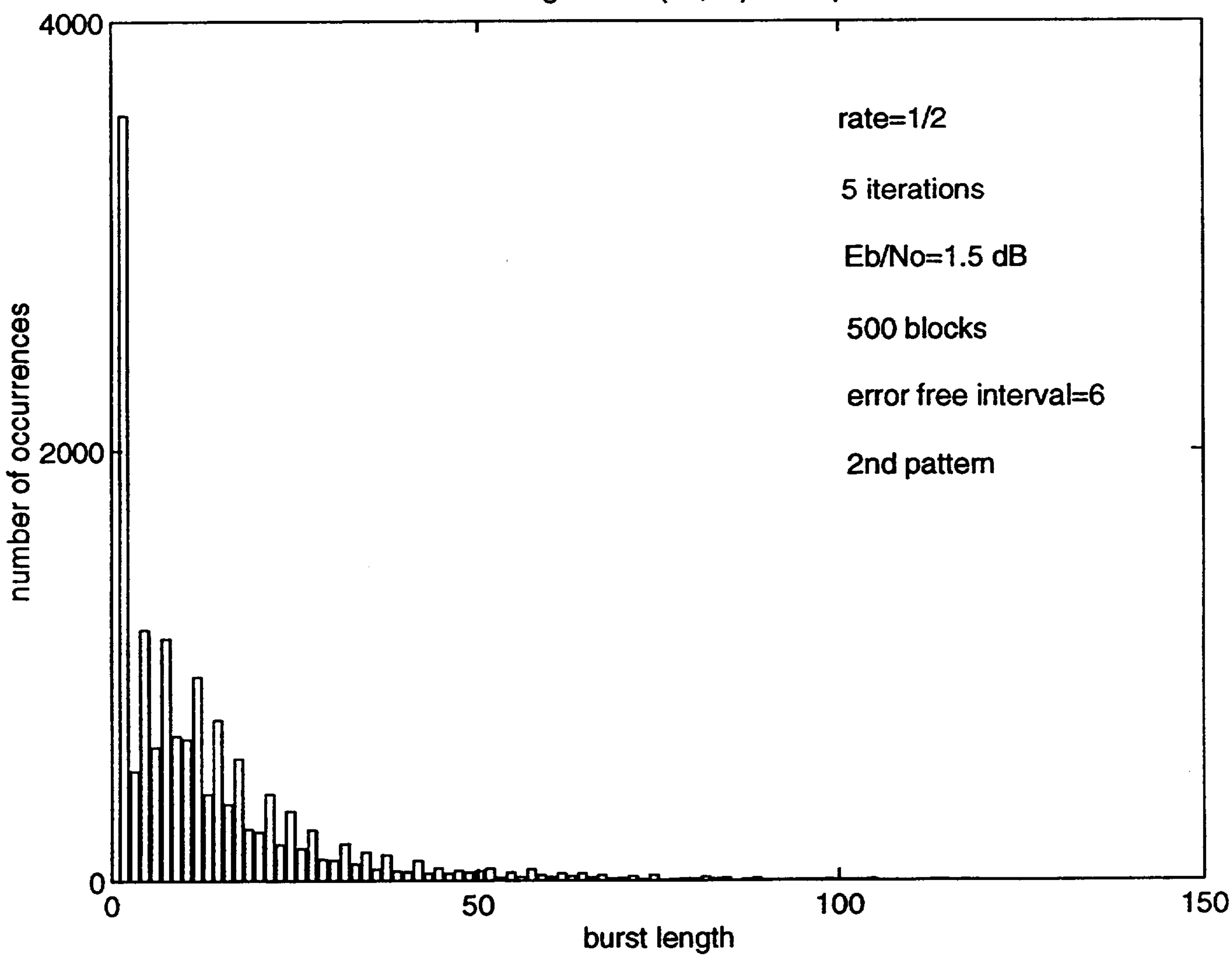
# *BURST ERROR RESULTS with The (31,37) TRANSPARENT CODE (cont'd)*

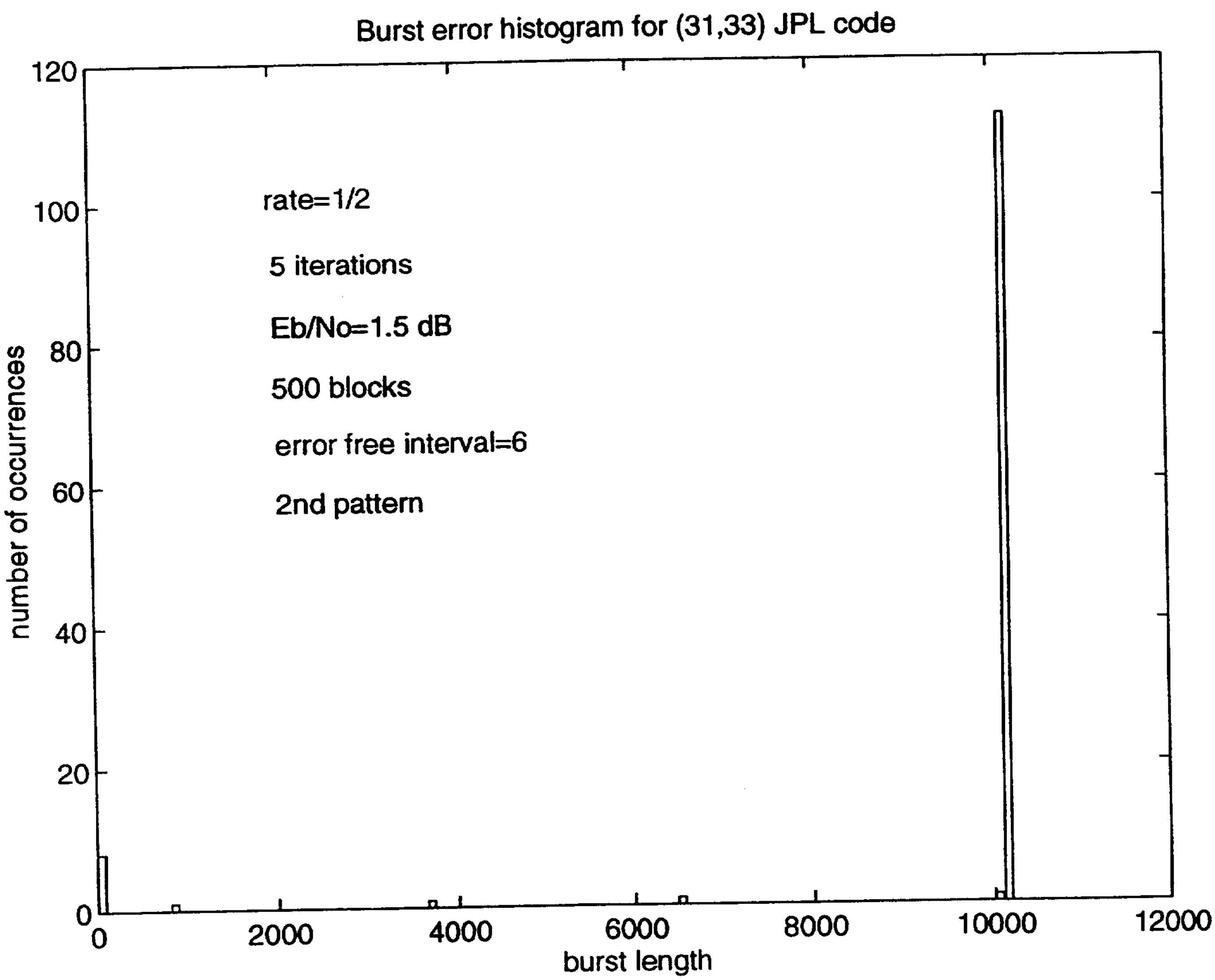
*N=1000, *Eb/No=2dB,

*5 iterations *for 500 error events

| Pattern/ # of burst err. | # of errors | Pe (bit) 1e-2 | PB (sym) 1e-2 | # of blocks |
|---|---|---|---|---|
| 1st pattern / 0 burst error | 106404 | 2.12 | 6.22 | 503 |
| 1st pattern / 100 burst errors | 102801 | 2.31 | 6.57 | 500 |
| 2nd pattern / 0 burst error | 89950 | 1.77 | 5.75 | 507 |
| 2nd pattern /100 burst errors | 98716 | 1.97 | 5.63 | 500 |

Burst error histogram for (31,37) Transparent code





Burst error histogram for (31,33) JPL code
rate=1/2
5 iterations
Eb/No=1.5 dB
500 blocks
error free interval=6
2nd pattern
number of occurrences
burst length
0
20
40
60
80
100
120
2000
4000
6000
8000
10000
12000

# PERFORMANCE OF TURBO CODES IN PULSED CW RFI

William E. Ryan, Assistant Professor
New Mexico State University

March 1997

# OUTLINE

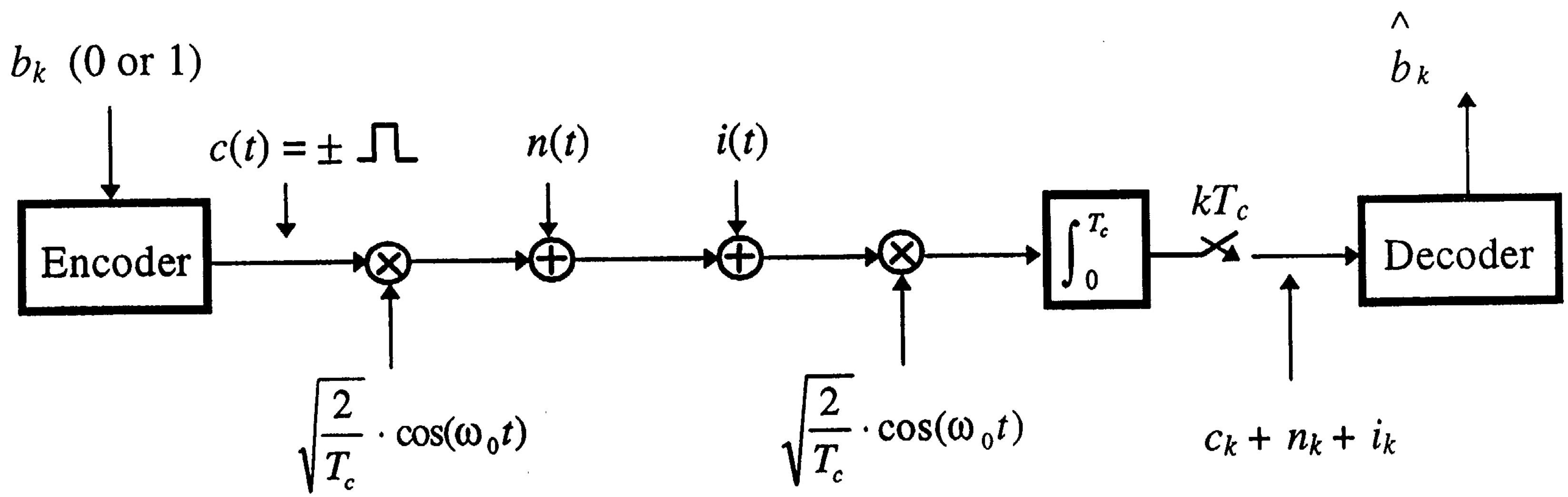
I. RFI Model

II. Simulation Results

III. Future Work

# I. RFI MODEL

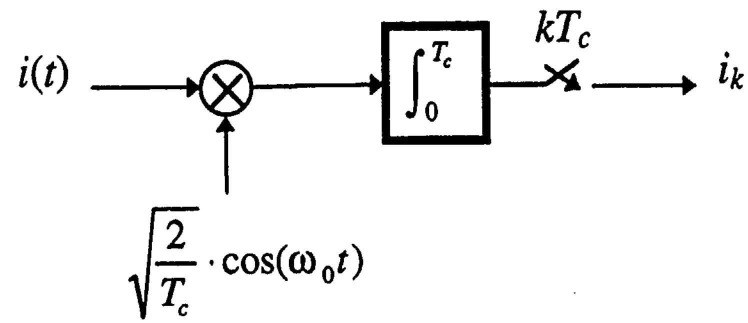
## Model of turbo-coded BPSK channel in AWGN and RFI




$$
\text{where, for CW RFI,}\quad i(t) = a \cdot \cos(\omega_I t + \phi) \quad \text{for} \quad \tau_1 < t < \tau_2
$$

$$
= 0 \quad \text{otherwise}
$$

## RFI component at sampler output



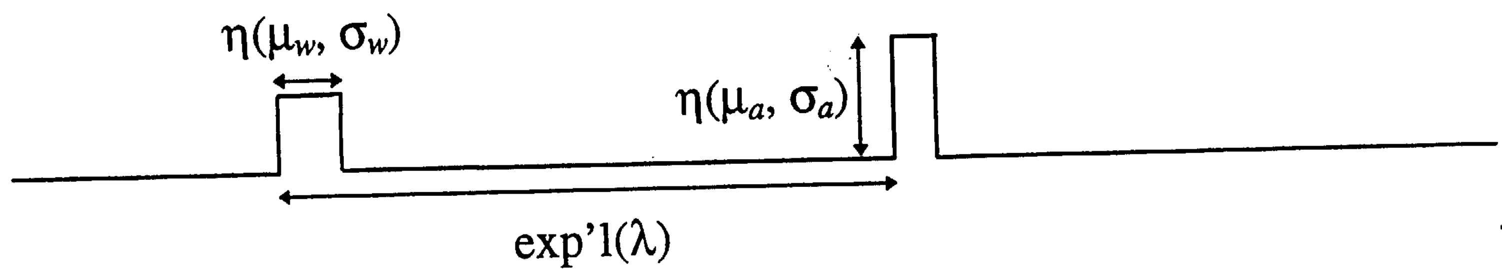

$$i_k = \int_{\max(\tau_1, kT_c)}^{\min(\tau_2, (k+1)T_c)} a \cdot \cos(\omega_I t + \phi) \cdot \sqrt{2/T_c}\cos(\omega_0 t)\, dt$$

$$= \frac{a}{2\Delta\omega}\sqrt{2/T_c}\sin(\Delta\omega\, t + \phi)\Big|_{\max(\tau_1, kT_c)}^{\min(\tau_2, (k+1)T_c)}$$

where $\Delta\omega \equiv (\omega_I - \omega_0)$ and $-2\pi/T_c \le \Delta\omega \le 2\pi/T_c$ .

## RFI statistics

1. Poisson arrivals $\Rightarrow$ exponential inter-arrival times: exp'l($\lambda$)
2. Gaussian widths (durations): $\eta(\mu_w, \sigma_w)$
3. Gaussian amplitudes: $\eta(\mu_a, \sigma_a)$
4. $\Delta\omega$ is uniformly distributed on the interval $(-2\pi / T_c, 2\pi / T_c)$



# II. Simulation Results

**Turbo Code**

JPL proposed (31, 33) turbo code - rate 1/2

N = 10200

5 iterations

**RFI**

RFI amplitude selected for SIR = -20, -10, and 0 dB

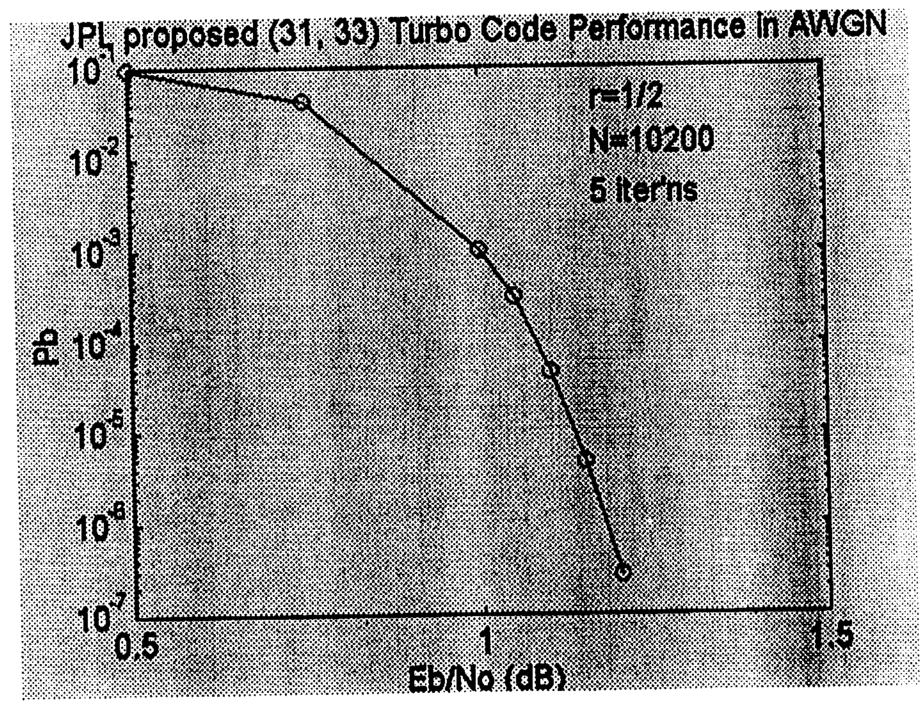
- Ex: $\mu_a = \sqrt{200} \Rightarrow \text{SIR}_{\text{ave}} = \dfrac{1}{(\sqrt{200})^2 / 2} = 0.01 = -20 \text{ dB}$

  $\sigma_a = 2$

RFI width

$\mu_w = 5\sigma_w$ so that $\Pr\{w < 0\} = Q(5) \cong 3\text{e-}7$

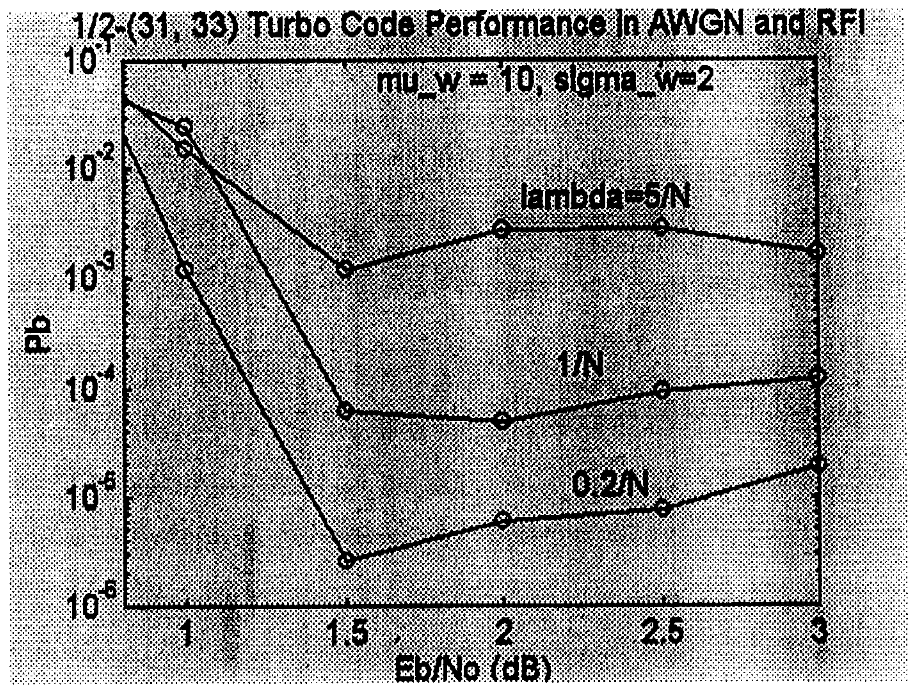
## **AWGN baseline**: 5 iterations



**AWGN + RFI** (5 iterations): **SIR = - 20 dB**

fix $\mu_w = N/1000 = 10$, $\sigma_w = \mu_w / 5 = 2$

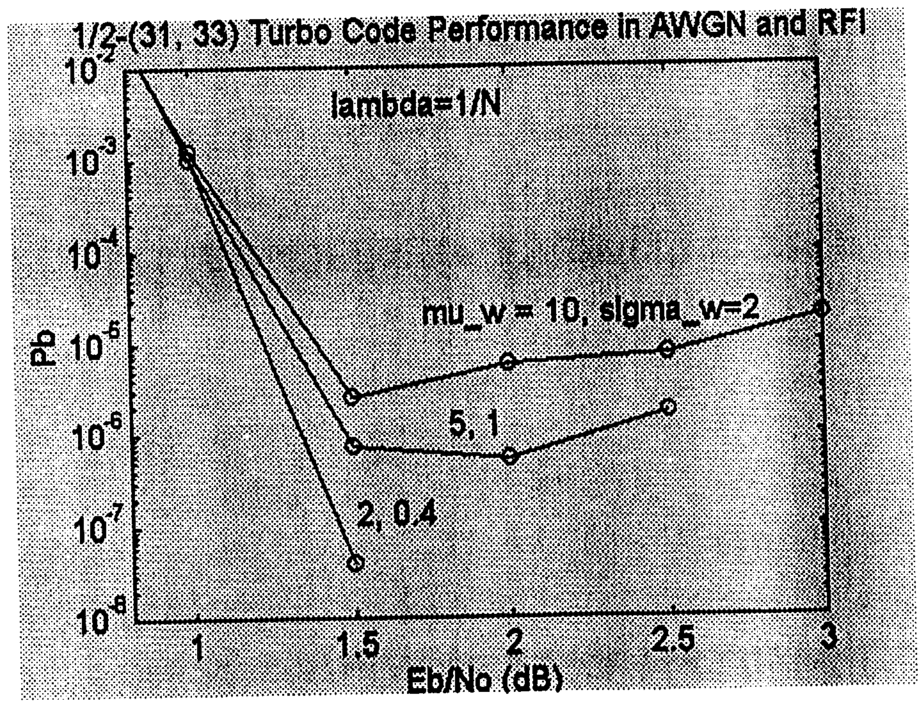
vary $\lambda = 5/10000, 1/10000, 0.2/10000$



**AWGN + RFI** (5 iterations): **SIR = - 20 dB**

fix $\lambda = 1/10000$

vary $\mu_w = 10, 5, 2$ $(\sigma_w = \mu_w / 5)$



**AWGN + RFI** (5 iterations): **SIR = - 20 dB**

fix $\lambda = 0.2/10000$

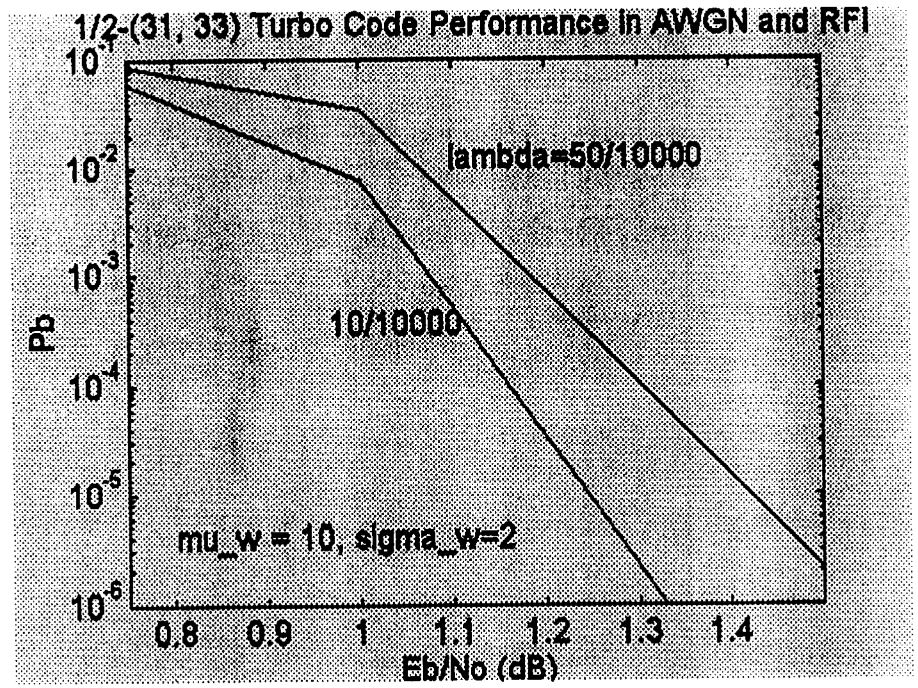
vary $\mu_w = 10, 2$ $(\sigma_w = \mu_w / 5)$

PERFORMANCE DEGRADATION IS NEGLIGIBLE

**AWGN + RFI** (5 iterations): **SIR = - 10 dB**
for $\lambda = 5/10000, 1/10000, 0.2/10000$
and $\mu_w = 10, 5, 2$ $(\sigma_w = \mu_w / 5)$

PERFORMANCE DEGRADATION IS NEGLIGIBLE

**AWGN + RFI** (5 iterations): **SIR = - 10 dB**
for $\lambda = 50/10000,\ 10/10000$
and $\mu_w = 10$ ($\sigma_w = \mu_w / 5$)



**AWGN + RFI** (5 iterations): **SIR = 0 dB**

PERFORMANCE DEGRADATION IS NEGLIGIBLE FOR

for $\lambda > 50/10000$ and $\mu_w > 10$

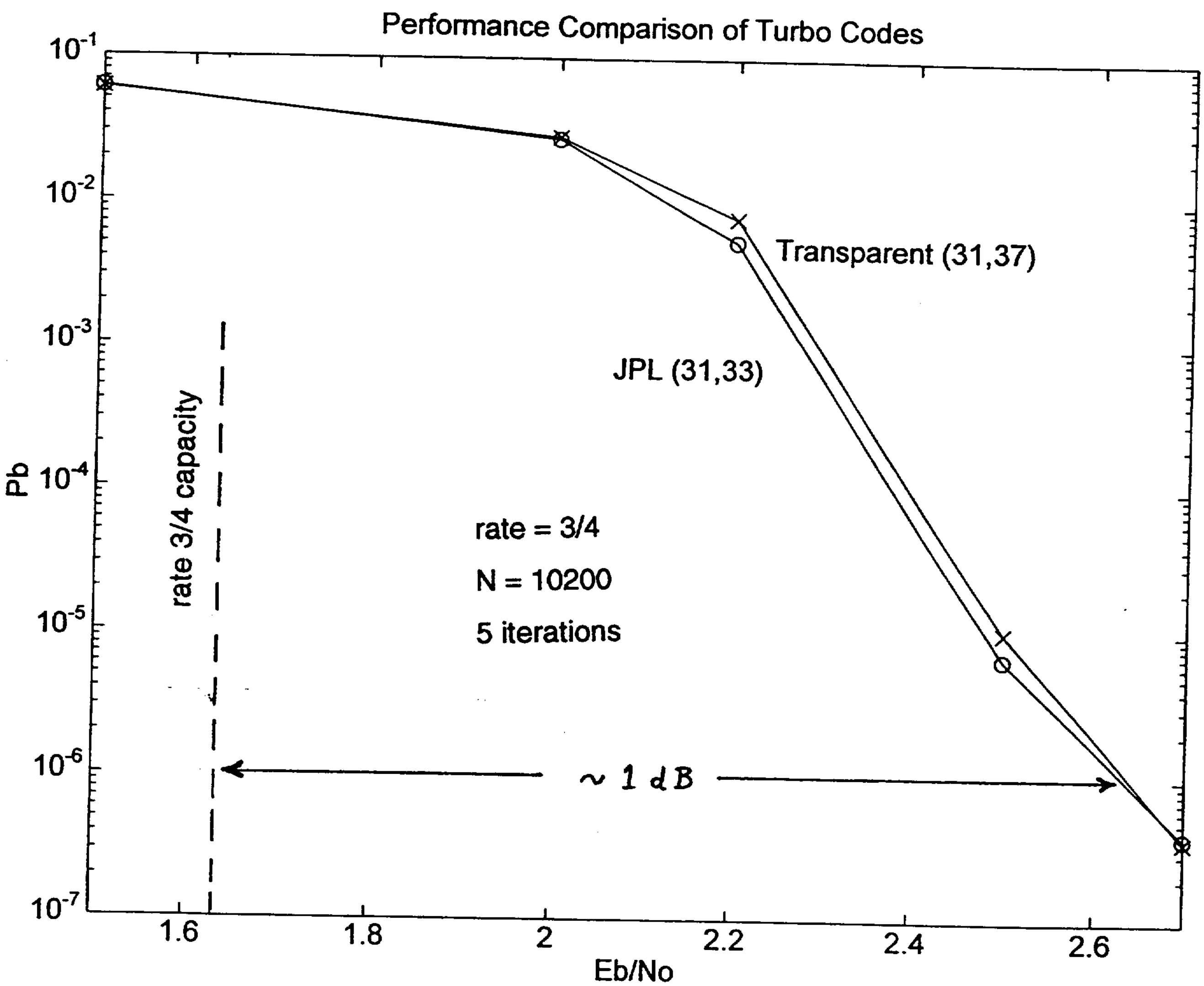
# *HIGH RATE TURBO CODES*

William E. Ryan, Asst. Prof., NMSU

Omer F. Acikel, Ph.D. Student, NMSU

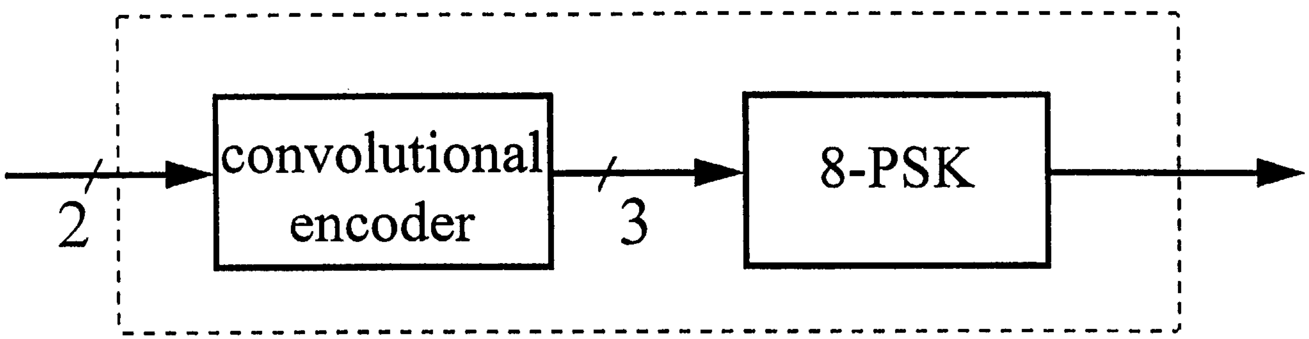
March 11, 1997

# Rate 3/4 Turbo Codes

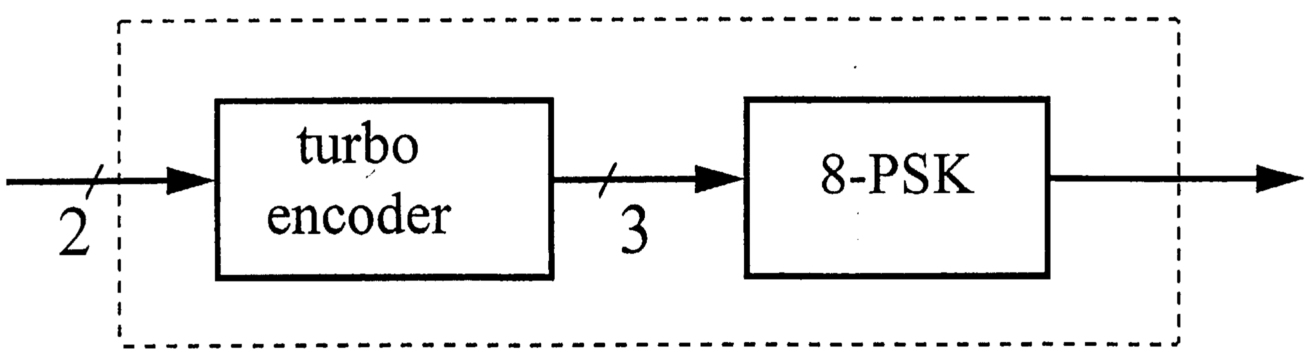


# *INTRODUCTION TO TURBO-TRELLIS CODED MODULATION (T-TCM)*

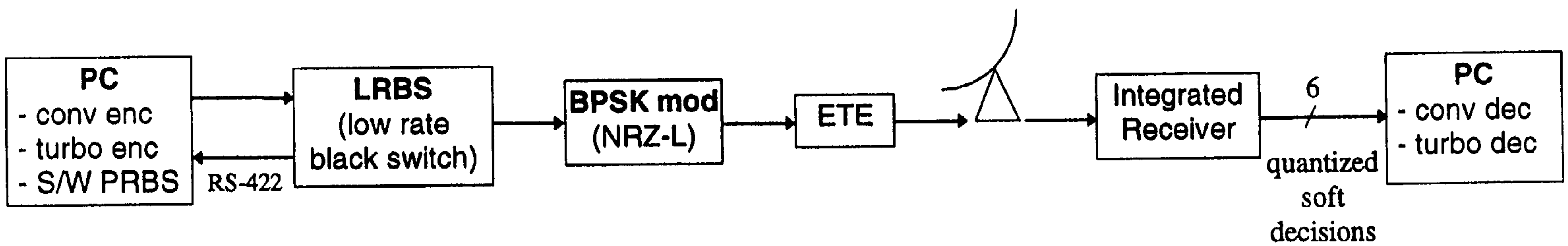
## 8-PSK TCM




## 8-PSK T-TCM



# TURBO CODE TEST THROUGH TDRS




- will run the r=1/2, K=7, conv code for a baseline
- the turbo code will be the r=1/2 (31,33) code proposed by JPL
- all encoders and decoders will be simulated in software
- software must be modified for block sync and to accept quantized soft decisions
- goal for first round of tests: $P_b$ vs $E_b/N_0$ curves down to about 1dB
- estimated time of completion for first round of tests is June 1997

# DAMA Carrier Acquisition

Phillip De León

*Assistant Professor*

***New Mexico State University***
***Klipsch School of Electrical and Computer Engineering***
***Center for Space Telemetering and Telecommunications***

# Background of Investigation

- Simulations indicate up to a ±64kHz Doppler shift on Small Satellite carrier
- Current receiver can recover/demodulate carrier with up to a ±3kHz Doppler shift
- Nature of proposed DAMA service SN does not provide a priori knowledge of Doppler shift of carrier

# Requirements for DAMA Carrier Acquisition

- Front-end hardware unit to
  - detect DAMA carrier
  - correct for Doppler shift
- DAMA carrier detection and correction should keep pace with service request rate
- Acquisition of service request should have minimal impact to WSC facilities

# Proposed Solution

- Use windowed, discrete Fourier transform (DFT) to detect carrier (peak spectral detection)
- Pass frequency estimate to receiver for demodulation
- Implement solution using digital signal processing (DSP) hardware

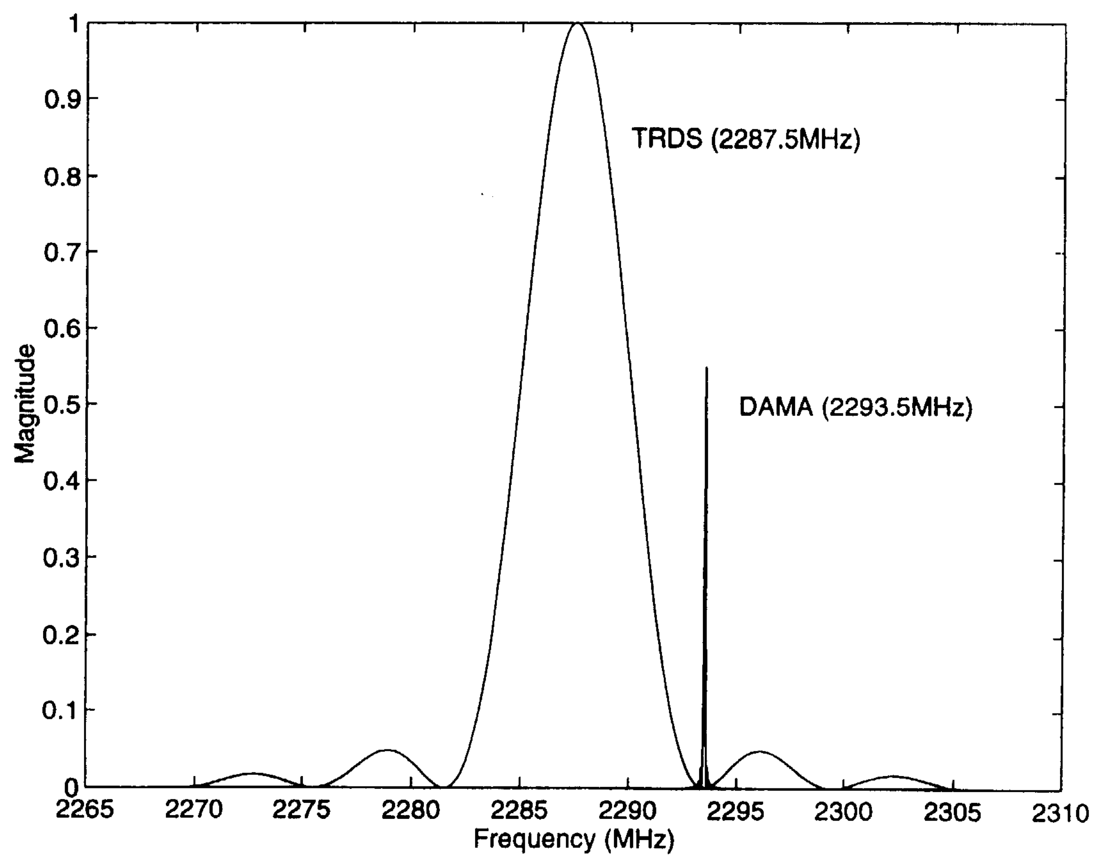
# DAMA Carrier Acquisition Prototype Unit

- Hardware unit built around 40mips Motorola DSP56002 processor
- Reliable frequency estimation to within ± 23Hz over a 24kHz bandwidth
- Reliable frequency estimation down to –4dB SNR
- Approximately ~200μs for estimate (assuming prior data acquisition)

# Proposed Specifications

- DAMA carrier located in frequency at first null in TDRS spectrum (2287.5MHz + 6MHz)
- Main lobe bandwidth of 200kHz in DAMA spectrum

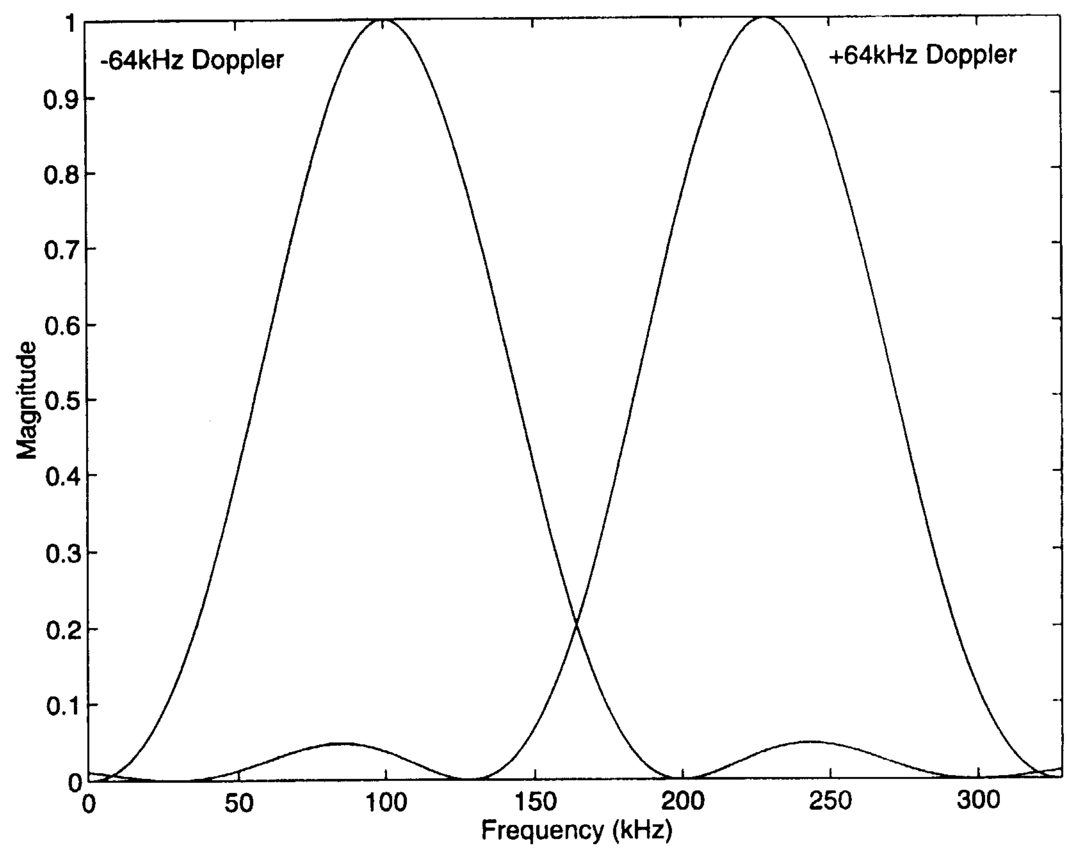
# DAMA Carrier Location



# Proposed DAMA Carrier Acquisition Unit

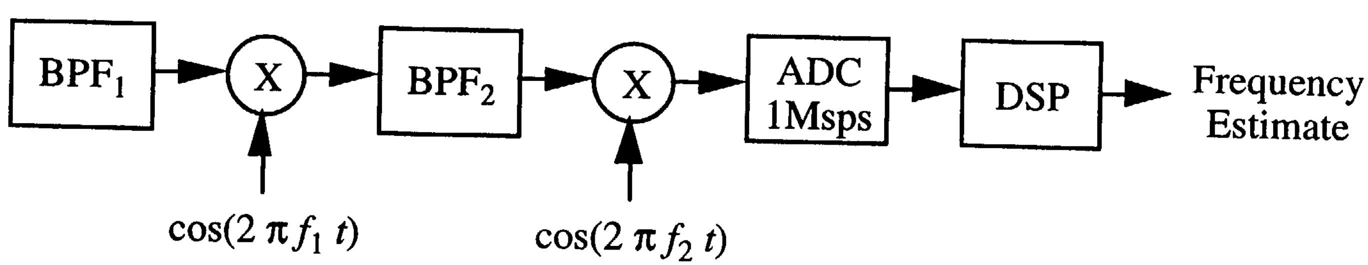
- Bandpass filter and frequency-shift DAMA signal spectrum
- Main lobe of shifted spectrum preserved in 328kHz-wide band

# Shifted DAMA Spectra



# Proposed DAMA Carrier Acquisition Unit (con't)

- ±3kHz estimation accuracy requires 256-point DFT (1MHz A/D)
- Execution rate demands
  - ~100mips (100MHz Motorola DSP56301)
  - 64k external SRAM



# Proposed DAMA Carrier Acquisition Unit (con't)

- Frequency estimate delivered to receiver as
  - locking tone at estimated frequency (or some fraction of it)
  - voltage proportional to estimated frequency for driving a VCO

# Further Investigations

- Exploit knowledge of DAMA signal characteristics
  - more efficient frequency estimation, i.e. “modern spectral estimation”
  - (adaptive) parametric models (AR models) of DAMA carrier
- Service multiple DAMA requests

# Conclusions

- Problem is well-suited to DSP-based implementation
- Prototype hardware provides accurate, real-time frequency estimates
- Design of DAMA Carrier Acquisition Unit based on prototype and simulation data

# Non-linear Equalization of Non-linear Satellite Channels

**James P. LeBlanc and William E. Ryan**

Klipsch School of ECE
New Mexico State University

## Goals of Effort

- Increase data rate through TDRSS
  - Use of higher order modulation schemes
  - Higher symbol rates

## Methods

- Reduction of non-linear ISI due to TWT
- Use of adaptive non-linear equalization

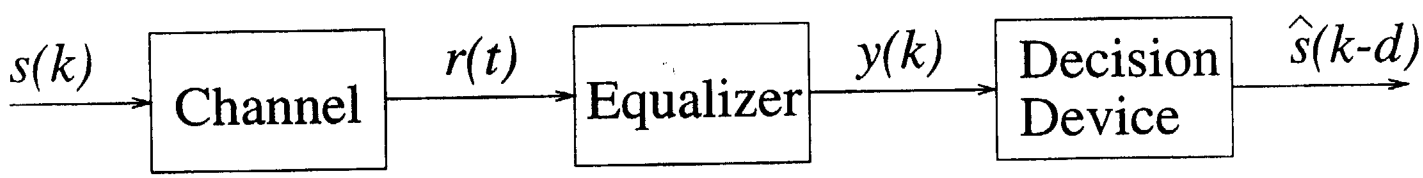
## Related Publications

- A. Gutierrez, W. Ryan *Equalization and Detection for Digital Communication over Nonlinear Bandlimited Satellite Communication Channels*, NMSU-ECE-95-008, 1995.
- T. J. Wolcott, W. P. Osborne, *Uplink-Noise Limited Satellite Communications Systems*, NMSU-ECE-95-014, 1995.
- W. P. Osborne, T. J. Wolcott, *Performance Evaluation of 8PSK at 450 MBPS Through TDRSS*, NMSU-ECE-95-004, 1995.

## Related Efforts

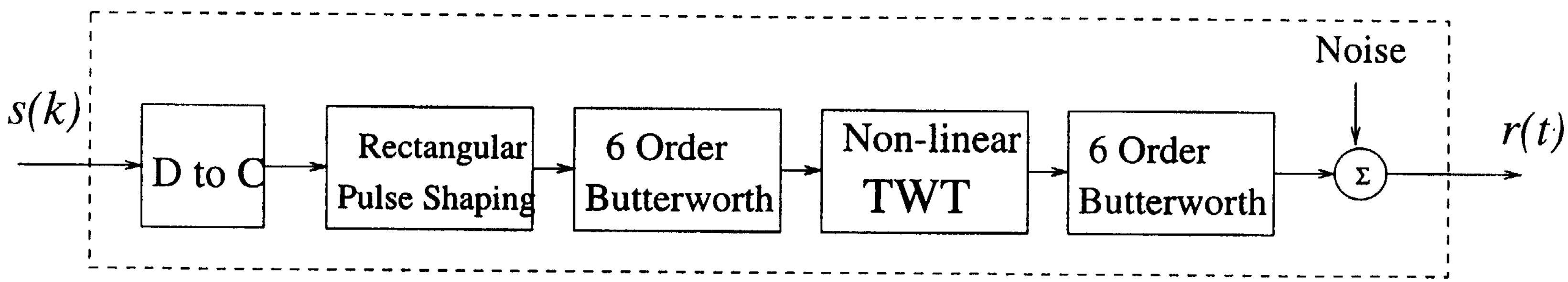
- Data acquisition (snapshots) of actual TWT channels from Loral
- In-house TWT channel implementation
- Loral has installed *advanced modem* at TDRSS ground station at WSMR incorporating nonlinear equalizer and higher order constellations

## System Block Diagram

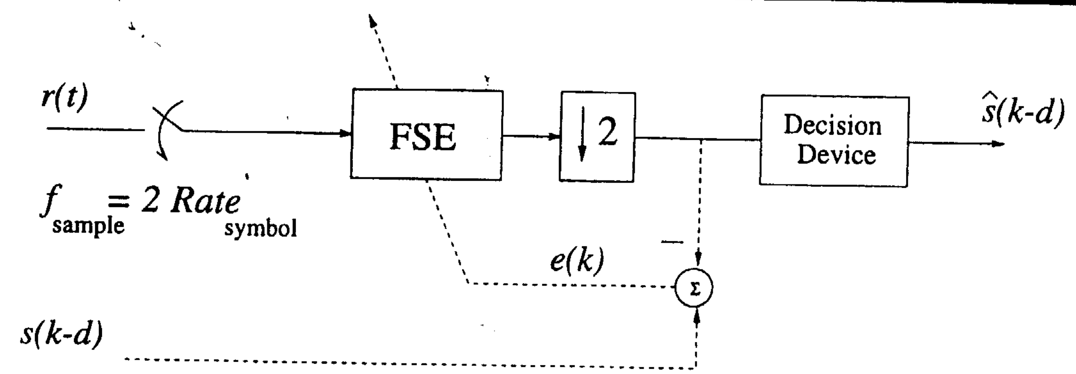



- *Channel* introduces noise and intersymbol interference (ISI)
- *Equalizer* reduces ISI (w/o excessive noise enhancement) ...
- ... allowing *Decision Device* to estimate transmitted symbol

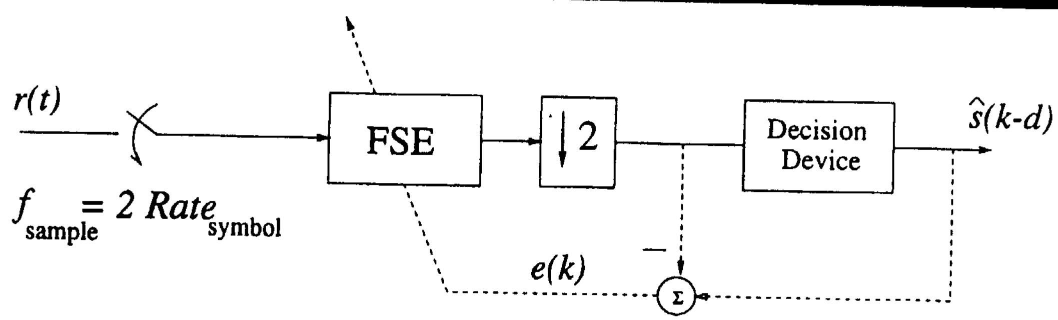
# Baseband Channel Model



## LMS Feedforward Linear Eq. (using training)




## Decision Directed Feedforward Linear Eq.

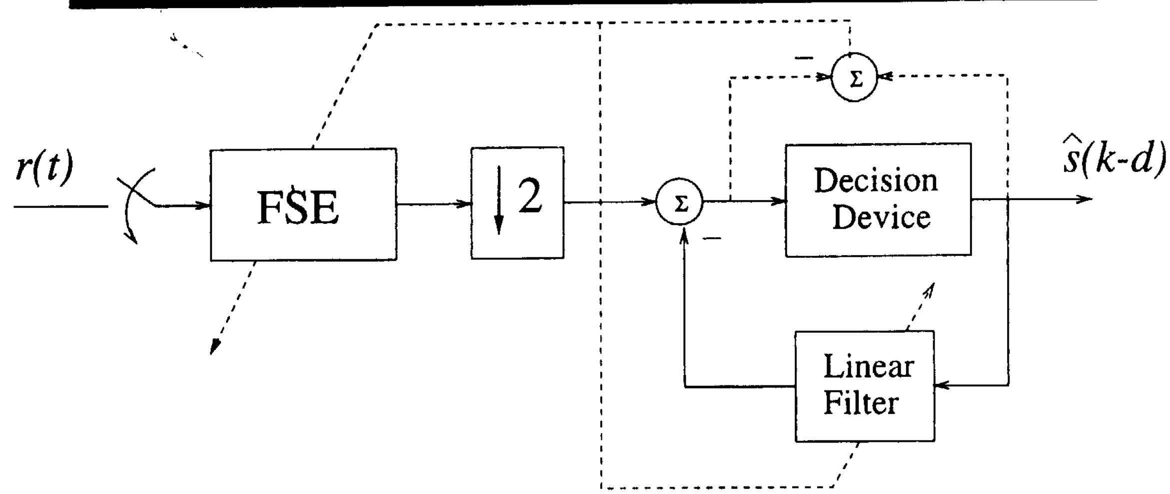



- Feedforward equalizers suffer noise enhancement
- Linear feedforward equalizers can't correct for non-linearities

## Adaptive Non-linear Feedforward Eq.

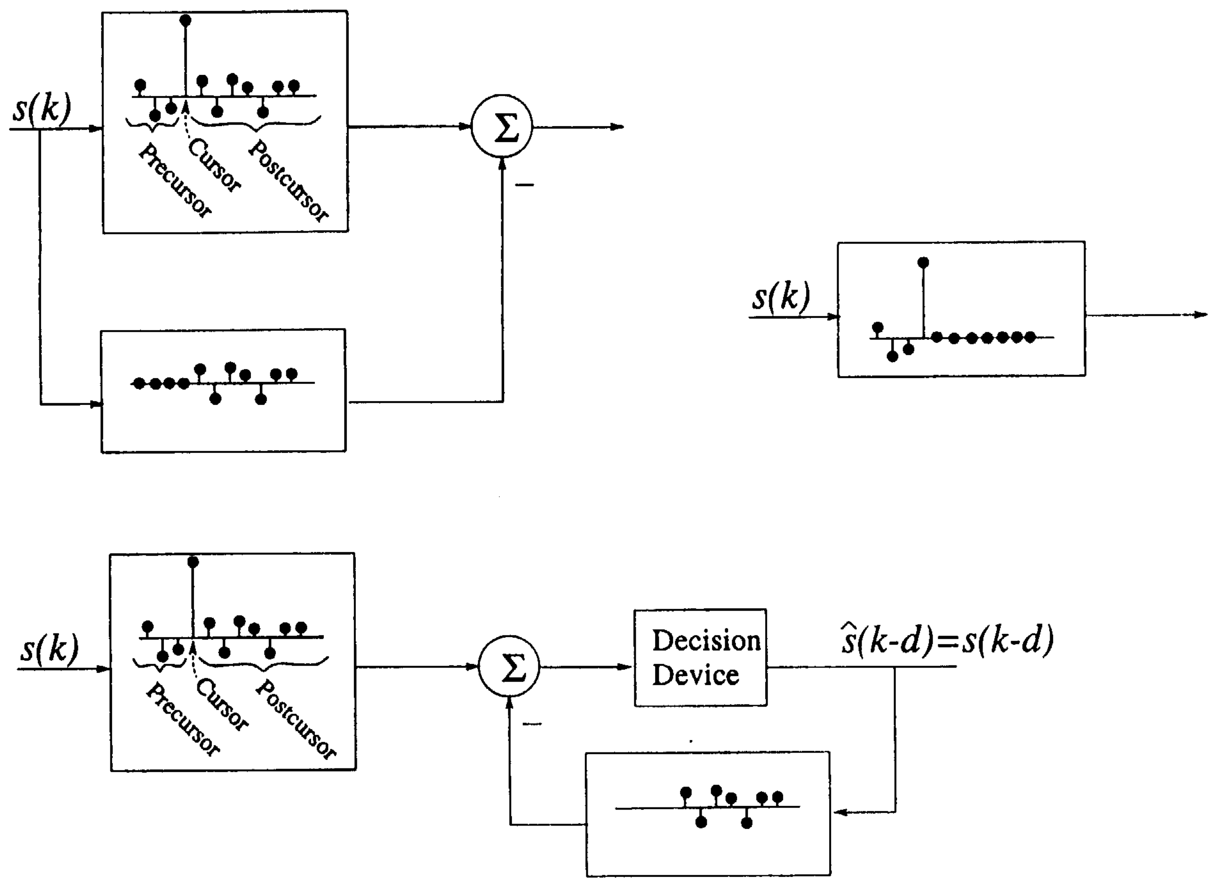
- Feedforward Non-linear equalizers may be implemented (for example, Volterra filters)
- These will exhibit non-linear noise enhancement

# Decision Feedback Equalizer (DFE)



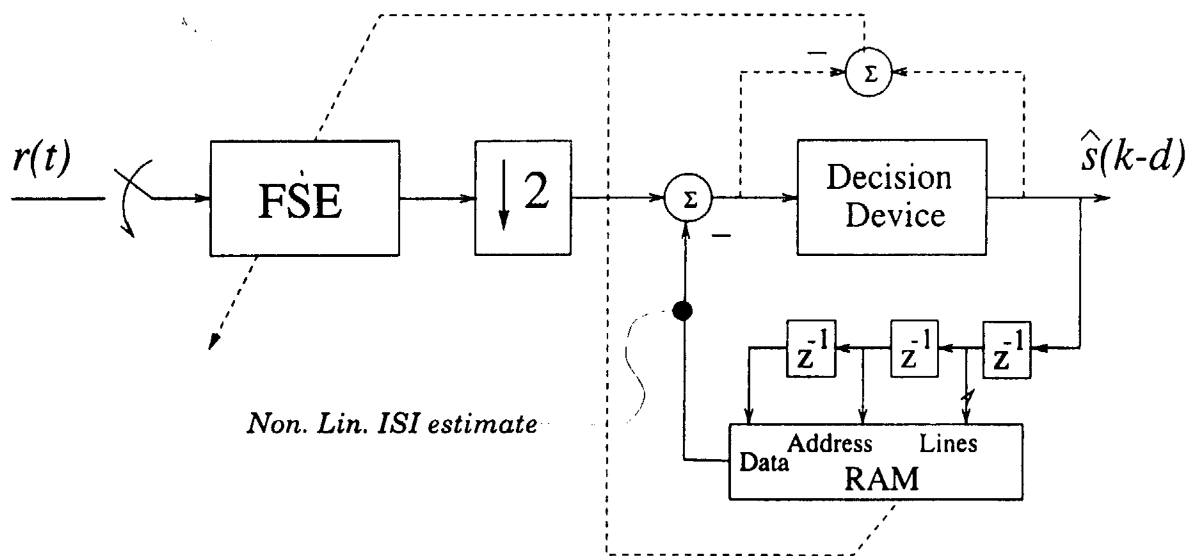

- DFEs do *not* suffer noise enhancement
- DFEs can cancel *only* post-cursor ISI (use with feedforward FSE)
- DFEs suffer from error propagation
- Linear feedback eq. can't correct for non-linearities
- Overall non-linearity makes analysis difficult

# DFE Attacks Postcursor

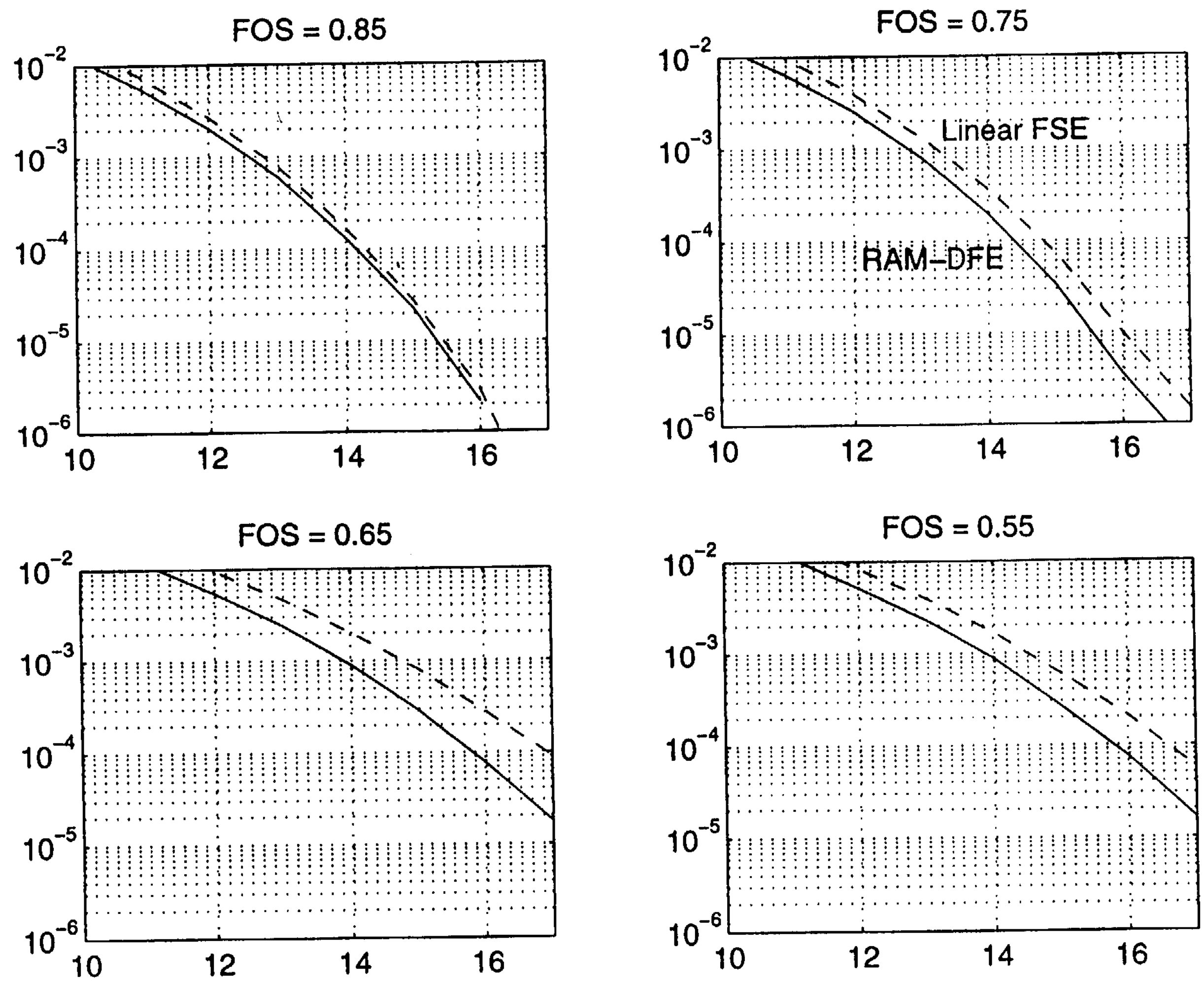



- DFEs can eliminate postcursor without noise enhancement ...
- ... if decision device output is correct

# RAM-DFE




- RAM-DFEs *can* correct for non-linearities
- RAM-DFEs can be implemented without multiplies
- RAM-DFEs typically converge slowly
- Overall non-linearity makes analysis difficult



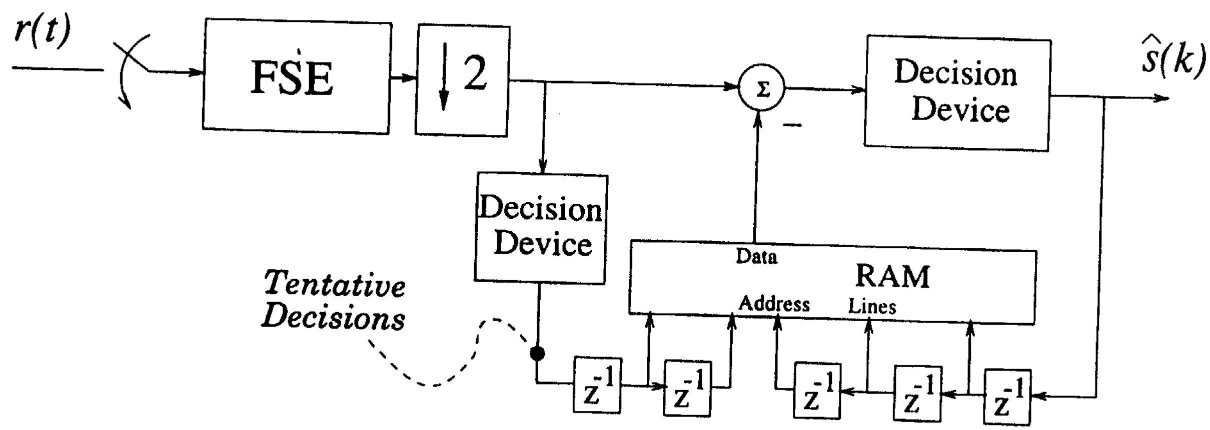

- Cutoff of Butterworth Filters is FOS (Fraction of Symbol Rate)
- 8-PSK Symbol Errors vs. SNR ($E_s/N_0$)

## Results

RAM-DFE performance over Linear FSE,

- is modest for low symbol rates
- improves for higher symbol rates
- *may* be further improved through use of a "RAM canceler"

# RAM Canceler




- Use of *tentative decisions* allows reduction of *precursor* non-linear ISI
- Introduces new error mechanism
- Overall performance impact under investigation

## Conclusions

- Increase in data rate through TDRSS *is* achievable using a combination of higher order modulation schemes and higher symbol rates.

## Specifically...

- Use of non-linear DFE (RAM-DFE)
  - mitigate noise enhancement,
  - reducing both linear and non-linear postcursor ISI.
- Linear Fractionally Space Equalizer
  - reduces linear precursor ISI.
- RAM-canceler with tentative decisions
  - reduces precursor nonlinear ISI components